S
625.72
H3rrd
1971
Vol.I

PLEASE RETURN

STATE DOCUMENTS COLLECTION

JUN 1 1978

MONTANA STATE LIBRARY
930 E Lyndale Ave.
Helena, Montana 59601

A REPORT

ON THE

ROAD DESIGN MANAGEMENT RESEARCH PROJECT

MONTANA STATE HIGHWAY COMMISSION

DECEMBER 1971

Roy Jorgensen Associates, Inc.

Montana State Library
3 0864 1006 6561 4

ROY JORGENSEN ASSOCIATES, INC.

Engineering and Management Consultants

POST OFFICE BOX 575
GAITHERSBURG, MARYLAND 20760

December 23, 1971

Mr. Harry J. Anderson, Director
Montana Department of Highways
6th Avenue and Roberts
Helena, Montana 59601

Dear Mr. Anderson:

We are pleased to submit this report on the Road Design Management Research Project.

The principal purpose of the project was to develop a systems approach to making management improvements in road design functions. This report has been prepared to summarize that approach. We believe it will be of significant value to the management officials of several state highway departments.

So that the management officials will be able to grasp the overall approach without the encumbrance of details, we have prepared a separate volume containing items of value to research personnel -- forms, tabulations and guidelines to research procedures.

In addition to the project report and the reference volume, research personnel should have access to copies of the Design Management Manual and the Design Manual -- both of which should be considered a part of this project report.

We appreciate very much the willingness of your Department to undertake this research.

Sincerely,

ROY E. JORGENSEN

PREFACE

The Consultant had two options in preparing this report -- writing for technical review and reference, or writing for top management guidance.

A top management report has been prepared -- meaning that most detailed tabulations and analyses have been omitted. The most pertinent findings, conclusions and results have been organized into a summary chapter, together with brief discussion chapters. A work plan for carrying out comparable projects elsewhere has been included in the final chapter.

The detailed tabulations and analyses are pertinent only to the Department and have been made available to the Department. Forms, procedures, guidelines and other items of value to agencies planning similar undertakings are available in a separate volume.

Management officials will find it of value to review the design management manual and the road design manual prepared for Montana as a part of this project -- both of which can be considered a part of this report.

Research personnel will find it best to use all four volumes as guides to undertaking projects of this kind.

FOREWORD

As most highway officials know, the meeting of letting schedules depends on two principal factors -- completion of the contract plans and acquisition of the rights-of-way.

This project was directed toward the contract plans factor -- through developing improvements in the road design management system.

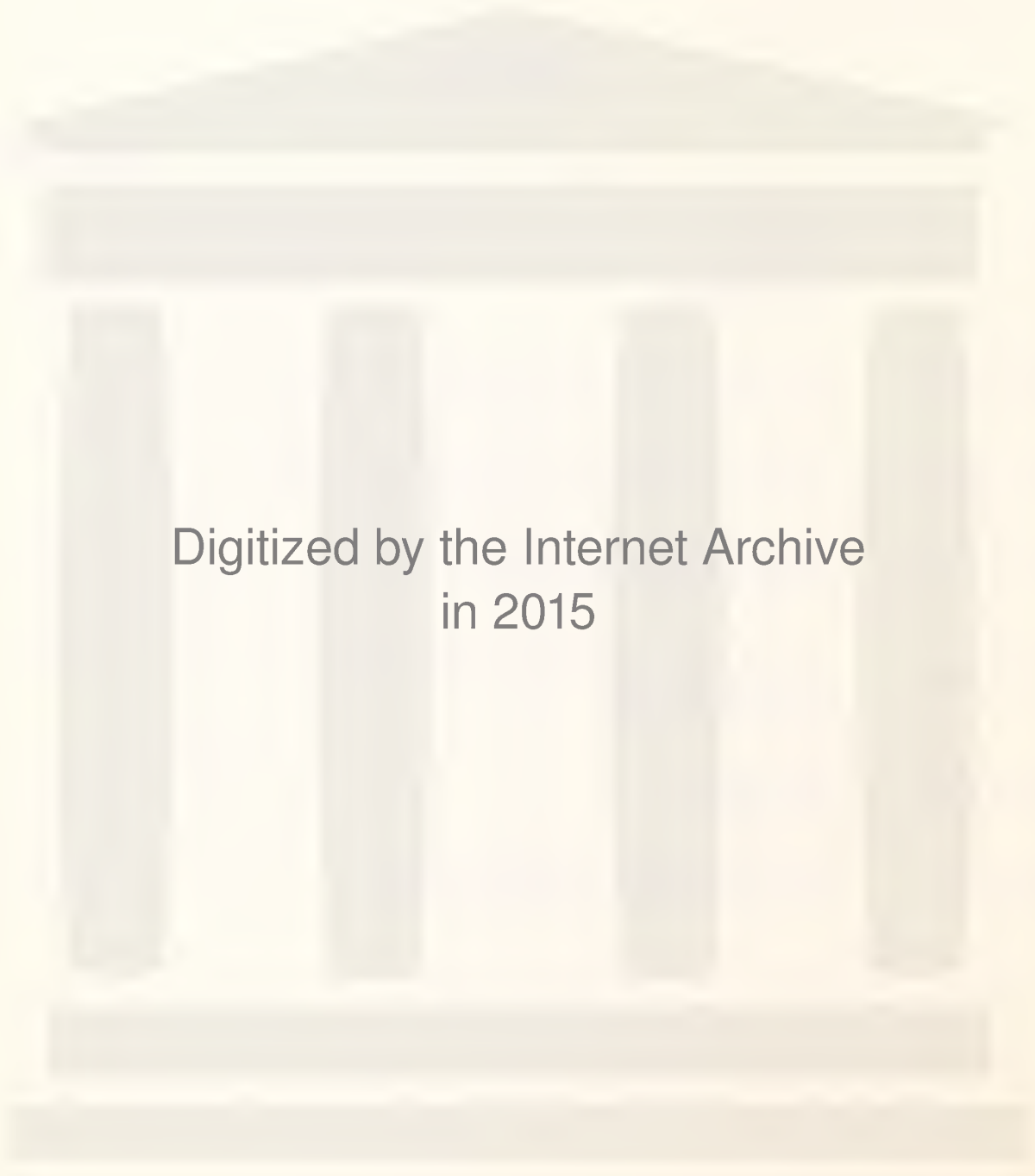
Design management improvements of many kinds have been initiated by most departments, such as redesigning the organization diagram, developing clearly defined lines of authority and statements of responsibilities, programming repetitive operations for computer performance, applying PERT and CPM techniques, and developing design manuals.

The Montana Department of Highways had limited success with one-at-a-time subsystem improvements -- such as applying a multiple-project scheduling system to the existing work methods and resource requirements. This project involved making improvements in all design management subsystems simultaneously, and in the system as a whole.

As is made clear in the report, improvements in each subsystem -- such as the work methods, contract plans, and the manpower management and personnel management subsystems -- affect all other subsystems. But the net result is an approach to design management improvements that can be of significant value to many agencies.

CONTENTS

		Page Number
	PREFACE	i
	FOREWORD	ii
Chapter One	OBJECTIVES AND SUMMARY OF RESULTS	1
Chapter Two	WORK SYSTEMS AND ORGANIZATION	11
Chapter Three	SCHEDULING AND CONTROLLING ROAD DESIGN PROJECTS	27
Chapter Four	PERSONNEL CLASSIFICATION AND SALARY PLANS	49
Chapter Five	TRAINING	67
Chapter Six	RECOMMENDED PROJECT PLAN	87


Digitized by the Internet Archive
in 2015

https://archive.org/details/roaddesignmanage1971royj

Chapter One

OBJECTIVES AND SUMMARY OF RESULTS

OBJECTIVES

The principal objective of this research project was to develop new techniques for improving road design management systems. The sub-objectives were to develop techniques for:

1. classifying and measuring the work loads, as represented by essential work, connected with the road design functions.
2. establishing the manpower resources required to accomplish the work loads.
3. establishing a system for scheduling and controlling the work loads and manpower commitments that will advance the work underway to the best advantage of management.
4. developing bases for consistently improving the levels of productivity.

SYSTEMS APPROACH

Any design management system consists of interrelated sub-systems.

The Sub-Systems

The Montana sub-systems consisted primarily of the following:

- The work processes
- The planning and scheduling system
- The design function organization
- Manpower management -- or manpower resource utilization
- Personnel management -- or the terms of employment
- The managerial policies and procedures for the design function
- The design manual
- Completed sets of contract plans
- The standard drawings
- The initial, intermediate and final plans reviews
- The manual work methods
- The electronic work methods.

The individual sub-systems and the design management system as a whole were analyzed and improved as the basic research approach.

Related Systems

In addition to the road design sub-systems, certain non-road design systems affect the design work processes. These include those connected with the long-range planning function, the five-year program function, and the soils exploration, hydraulics, bridge design, traffic engineering and right-of-way acquisition functions.

The scope of the research was limited to the road design function. Related systems were investigated only to identify the input requirements for road design and the output requirements from road design.

ROAD DESIGN FINDINGS

Contract Plans

The contract plans represent the completed work of the road design function -- and serve as a principal source of information relative to the incremental sub-divisions of the work.

The Department's road plans represented significant non-essential work loads, and the creation of additional non-essential work loads for the construction function and the contractors. The principal contributions to non-essential work loads were:

- The use of identical terms, abbreviations and symbols to mean different things, and different terms, symbols and abbreviations to mean the same things--creating confusion.
- Repetition of the same information on different plan sheets -- sometimes several times.
- Inclusion of non-useful information on most plan sheets.
- Ommission of certain items of essential data.
- Ineffective and incomplete indexes to the contents of the plans and the locations of data within the plans.

Standard Drawings

The Department's standard drawings also represented, to some extent, non-essential work loads:

- The content of the standard drawings included non-essential information.
- The drawings were unnecessarily difficult to use, since data for a single subject matter were often found on several sheets.
- Standard drawings were prepared for many varied purposes such as: to communicate design details to persons having to construct a project, to communicate design policies and criteria, to supplement information in the standard specifications, and to reduce the need for or supplement special provisions.
- The format of the drawings made the data presented difficult to read and interpret.
- Certain needed drawings had not been developed.

Work Methods and Processes

The methods used to accomplish the same work varied so much from design crew to design crew that they could not successfully be identified and diagrammed.

The work sequences and processes also varied--to the point where sequence diagrams could not be created to represent the existing situation.

Scheduling System

The Department had developed, and abandoned, a Critical Path Method of project scheduling.

A scheduling system existed. It indicated planned completion dates by design phase and project status expressed as a percentage of work completed on each project. It did not compare actual accomplishments with planned accomplishments or actual costs with planned costs. It did not indicate priorities by project.

Design engineers could, and did, work out their own priorities with regard to projects to be completed. The system itself made this a logical practice.

Manpower Management

The design function was carried out by a series of specialized individuals and crews.

Work sampling revealed that utilization of the productive time varied widely and for the most part, was well below acceptable levels. This was caused primarily by the excessive use of specialists and the use of fixed-size design crews--it being unusually difficult to schedule work units in ways that fully will utilize the time of specialists and fixed-size crews.

Personnel Management

Only positions were classified--as distinguished from employees.

Salary levels ranged from 16 percent above prevailing rates to 35 percent below.

Salary increases were based on time--one step per year--rather than measured performance.

Promotions were based on examinations and Personnel Board reviews--as distinguished from demonstrated performance capabilities.

No training courses, other than those generally available through adult education programs, were available.

No basis existed for employee motivation--other than the occasional opportunities for promotion.

Design Manual

Few organized guidelines to design existed, and no assembly of guidelines existed.[1/]

Design criteria were available in memoranda, but these were not organized. A number of criteria were communicated orally, without documentation. Designers often had conflicting information on the same subject, and inadequate information on many subjects.

No one person or unit was responsible for keeping design guidelines and standards current.

Management Manual

An organization diagram and certain informal operating policies and memorandum-type procedures were available.

RELATED SYSTEM FINDINGS

Projects were added and deleted from the "programmed projects" at frequent intervals. If a design project neared completion, through a priority system worked out by a designer, it was scheduled for letting--and it became a high priority project for the Department.

1/ The Department fully recognized the need for a design manual, had attempted to prepare one, but could not spare the needed manpower.

Surveys were completed on schedules established by the districts. The needs of the design engineers certainly were considered, but were filled as time became available rather than on a planned schedule.

Soils surveys were completed on a time-available basis.

CONCLUSIONS

One--The overall efficiency of the design function needed improvement--significant improvement.2/

Significant quantities of non-useful work were being accomplished. Personnel and units had frequently to wait for work loads. Every sub-system of the function needed simplification and modernization. The system as a whole was inefficient.

o o o o o o o

Two--No single effort, such as the establishment of a firm construction program or reorganization of the design function, would have had an appreciable effect on productivity.

The basic instruments of design had to be worked out first--such as a model set of contract plans, a complete and useful set of standard drawings, effective work methods, and a guide to the adopted work methods. Work load and manpower relationships had to be established. Ways of shifting the manpower to the work loads--as against moving work loads to fixed complements of manpower--had to be developed. A system of scheduling and controlling the work loads and manpower commitments was needed. And, among other things, a management reporting system was essential.

o o o o o o o

Three--The road design function was over-staffed--due to the management system that existed.

2/ Statistical data on productivity were collected and are available. They have not been included above because they would be misleading to persons not intimately familiar with the operation.

Significant volumes of non-essential work, repetitive work and make-work were being done. Productive time was being spent on work that could have been reduced in volume by adopting effective work methods, by using better standard drawings, and by defining the work to be done before each plan review. Most important, the decision-making process was out of sequence--creating unusual volumes of repetitive and non-productive work.

o o o o o o o

Four--Motivation for improving productivity could be created.

The employees could be given enough work to do, useful work to do, and effective work methods to use. Fully competitive salaries could be paid without increasing design costs--by decreasing the number of persons employed, through attrition, and by using the savings to finance needed salary increases. In most cases, salary increases could be based on performance--subject to a change in Department policy.

o o o o o o o

Five--Key employees would need to participate in the improvement efforts.

The road design management system was unnecessarily complex, but any final system would, despite significant simplification, still be complex. Any system imposed upon the personnel would be understood only in part--and key persons would work out their own changes. If a new system was to work, it would have to be fully understood and supported by the persons who were to use it--meaning those persons had to participate fully in its creation.

RESULTS

Specific Results

Effective work methods and work processes were developed--and placed in a design manual. The design of the manual itself was tested to ensure that the language levels, sentence structures, drawings, contents, organization characteristics, and index system were best suited to the users.3/

3/ The design manual itself is unique--in that it is based on carefully developed and tested performance standards and work methods, rather than on existing methods.

Manpower utilization guidelines were developed--and included in a design management manual.

A new system of scheduling and controlling work loads and manpower commitments was developed.

A model set of contract plans was completed--to represent the quality and quantity standards to be met.

A complete set of standard drawings was developed.

A new personnel classification plan was created--based on the position classification system in those cases where productivity would not affect the numbers of persons employed, and on the employee classification system where it would.

A new salary plan and salary management plan were developed--based on prevailing rates and on performance measures.

A management reporting system, based on exception reporting, was created.

General Results

As would be expected, three management objectives were attained:

1. The production level of the road design function is being improved.
2. The capability of management to plan and schedule design production, and to control costs, was improved.
3. The overall manpower needs are being reduced.

No specific relationships between work load inputs and manpower requirements have yet been developed--and cannot be developed, except for certain incremental parts, for at least two years. The project time permitted completion of many improvements, and refinements of selected improvements. At the time of this writing, the design manual and the design management manual have yet to be printed. The scheduling, controlling and reporting system has been tested, but the needed computer programs are incomplete. The personnel classification and salary plans are ready for implementation--but must be delayed for another month or two

so that comparable plans can be adopted on a Department-wide basis, and training programs must yet be developed.

Principal Result

The principal objective of the research was attained. An approach to improving road design management systems was worked out. (See Chapter Six.)

Chapter Two

WORK SYSTEMS AND ORGANIZATION

Organizations are developed to facilitate work performance. They are designed, or their designs are adjusted, to meet the needs of work systems and work load requirements. This chapter describes (1) the analyses made of existing work systems, (2) the improvements made in the systems and (3) the recommended changes in organization based on these analyses.

WORK SYSTEMS ANALYSES

Work systems analyses and improvements were undertaken in three steps -- existing systems identification, work requirements standardization, and step-by-step improvements.

Existing Work Systems

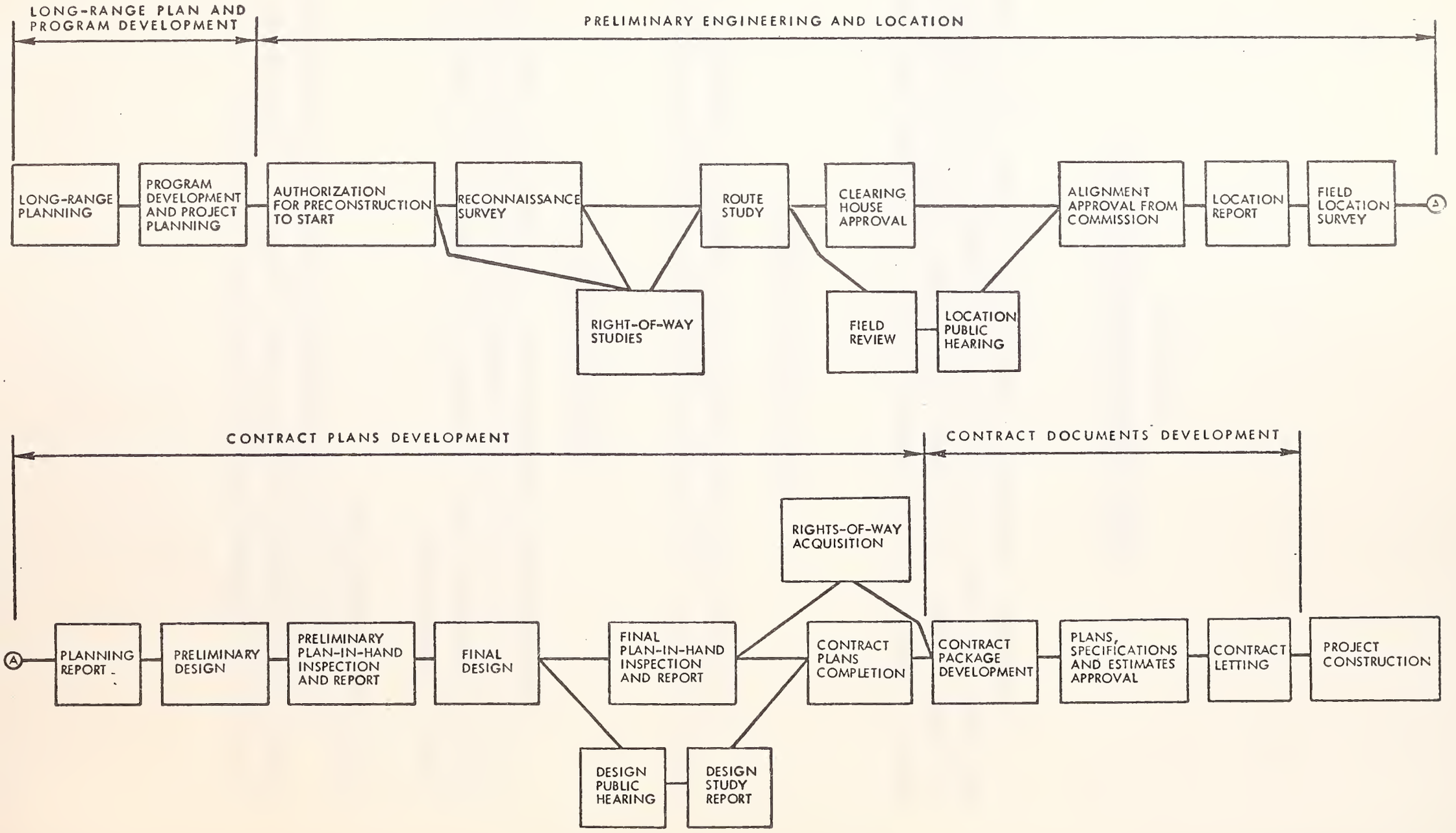
Initial project efforts were directed toward identifying the major work elements of the total preconstruction function. This was followed by more detailed analyses of those systems which had major impacts on road design, and a detailed task-by-task analysis of the road design work methods.

Preconstruction Summary System

The summary work flow of the preconstruction function from long-range planning through the letting of projects to contract is shown in Figure 1. The scope and major work requirements were defined for each of the elements shown in the work flow.

Figure 1

EXISTING PRECONSTRUCTION FUNCTION



Interrelated Systems

Figure 2 shows the network developed to summarize existing methods of project scheduling, progress monitoring and program revision. Similar, less detailed, analyses were made of the long-range planning, preliminary engineering and location studies, right-of-way and construction functions, and the ways they affect or interrelate with road design.

Detailed Road Design Analyses

Task-by-task work flow charts were developed for the internal and consultant road design functions. No single work system existed, nor did even a general pattern of a system exist. Separate units of road design personnel had developed their own methods and work sequences.

Several of the individual approaches were identified in sufficient detail to provide a basis for analysis.

Work Requirements Standardization

Work standardization included (1) standardization of the format and content of contract plans, (2) analysis of standard drawings and road design standards, and (3) development of two manuals to document improvements and to guide design personnel in their use.

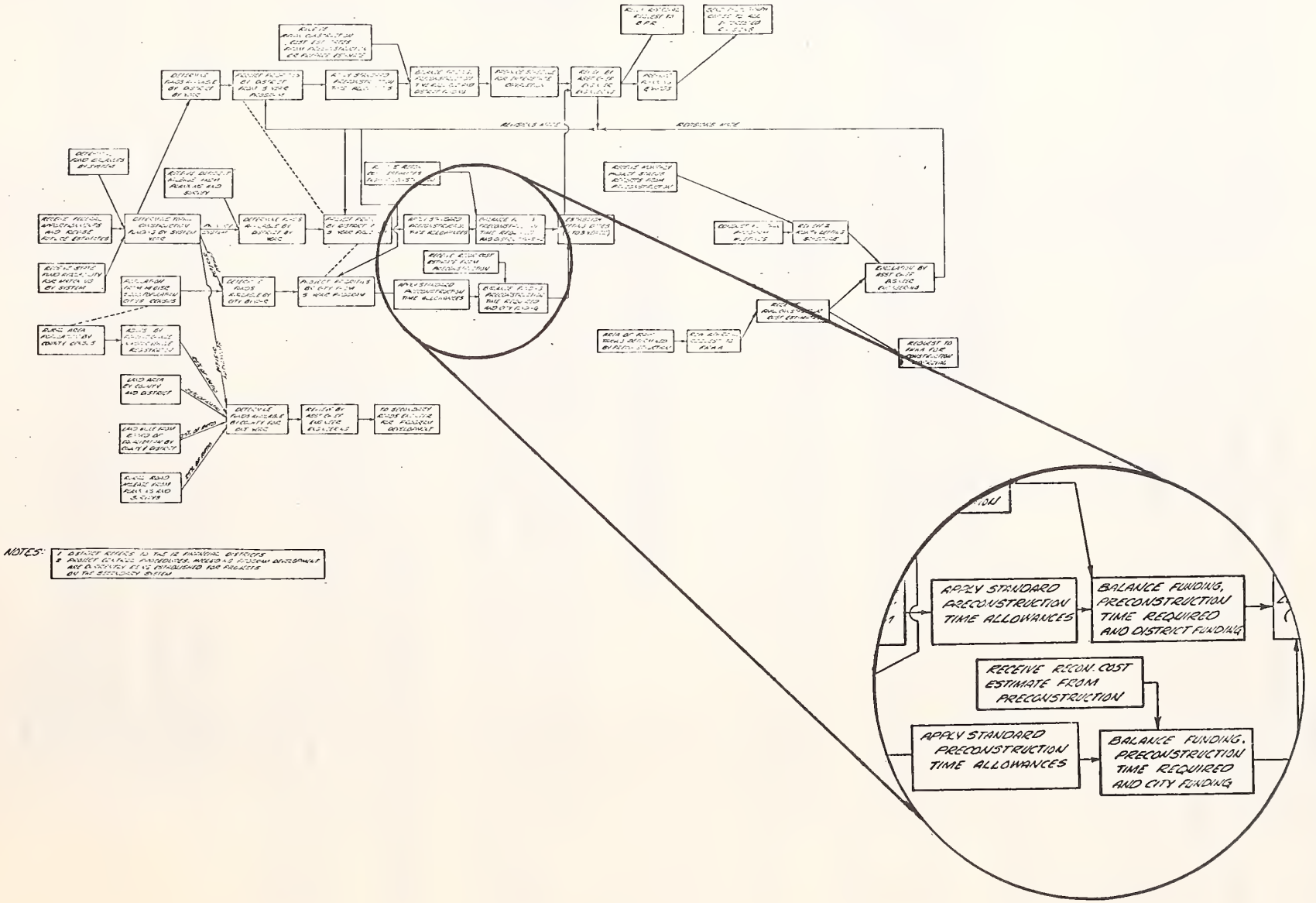
Standardization of Contract Plans

Every aspect of contract plans was reviewed in detail with the assistance of a committee composed of road design personnel. The principal characteristics of the unimproved contract plans are listed below:

1. Only a general pattern was followed in sequencing plan sheets in any set of plans; even this pattern was not followed consistently.
2. The system used to number sheets created serious difficulties with regard to ensuring that plan sets were complete. Such numbers as 21A and 21B were used.

Figure 2

AN EXAMPLE OF SUMMARY FLOW CHART PROJECT PLANNING AND SCHEDULING


APPLY STANDARD RECONSTRUCTION TIME ALLOWANCES
BALANCE FUNDING, RECONSTRUCTION TIME REQUIRED AND DISTRICT FUNDING
RECEIVE RECON. COST ESTIMATE FROM RECONSTRUCTION
APPLY STANDARD RECONSTRUCTION TIME ALLOWANCES
BALANCE FUNDING, RECONSTRUCTION TIME REQUIRED AND CITY FUNDING
NOTES:

3. The indexes were incomplete. Information frequently had to be found by "thumbing through" the plans -- and several passes were necessary to ensure that omitted data actually were omitted.

4. Sheets often contained data which should have been located elsewhere -- but were included on the wrong sheets because (1) space was not available on the right sheets, (2) space was available on the wrong ones and (3) the total number of sheets used could be limited by using the available space.

5. Some sheets contained too much data for single sheets, making those sheets very difficult to read.

6. Identical symbols and abbreviations were used to represent different things, and identical things were represented by different symbols and abbreviations.

7. Many data were repeated several times in the same set of plans.

8. All sheets contained data no longer needed in the plans.

9. Useful, and some essential, data were omitted from the plans.

The findings summarized above led to three conclusions:

> One -- Difficulties in communicating design decisions to contractors and construction inspection personnel can be reduced or eliminated by adopting uniform ways of setting things forth in the plans: standard terms, abbreviations and symbols; standard plan sheet layouts; and standard plan-set organization.
>
> Two -- Difficulties, and much of the work involved, in preparing contract plans can be reduced by deleting non-useful and duplicate data, and by organizing the needed data.
>
> Three -- Training personnel to read and interpret contract plans is made unnecessarily difficult by inconsistencies in the ways design personnel set forth plans data.

A model set of plans was developed for use as a guide to the design personnel. This model, plus the standards and procedures to be followed in preparing contract plans, are now included in a design manual.

Standard Drawings

A sheet-by-sheet analysis of the standard drawings showed that 199 standard drawings were in the active-use file. During the 18 months preceding the analysis, 109 revisions and 28 deletions had been made. Since some construction was started under standards that had since been revised or deleted, some contractors, designers and construction inspectors needed access to more than 330 standard drawings.

A survey of the usage of the standard drawings by contractors, suppliers and designers was made:

- Twenty-seven percent of the standard drawings were not used, or rarely were used by design personnel.
- Thirty-seven percent of the drawings were used frequently by design personnel.
- Forty-eight percent were used frequently by contractors and by construction inspection personnel.
- Thirty-nine percent were used frequently by suppliers.

The number of standard drawings was reduced to less than 50. A policy on the development and use of standard drawings was adopted and implemented by the Department.

Model System

Each element of the detailed road design network was analyzed by working backwards from the desired result to the start of work on that element. This procedure identified opportunities for deleting steps, resequencing essential steps and standardizing the work processes.

The result of this work is a model road design network having the following characteristics:

- The scope of each major work element, the work sequence and work inputs necessary to its accomplishment are defined.
- The reviews and approvals required for work completions are identified in each work sequence, together with the respective approval authorities.
- The content and documentation requirements of each design work report are identified.

The detailed model network includes more than 240 tasks.

A summary flow chart of the model system is shown in Figure 3. A sample page of the detailed network, containing 40 tasks, is shown in Figure 4.[4/]

Work Analysis Conclusions

The work analyses led to three conclusions:

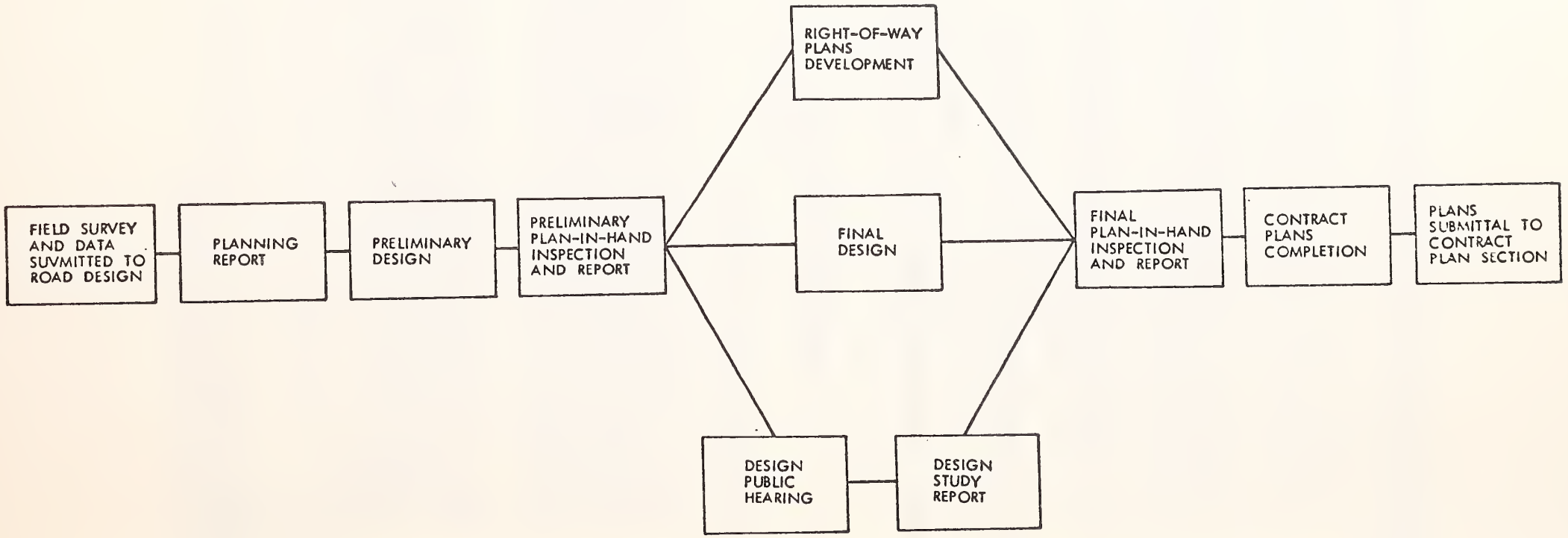
> One -- Detailed work analysis is the most important phase of a project of this kind. Since organizations are created and persons are employed to perform work, the work itself is the basic source of systems improvement data. In road design, the work systems are critical to every phase of the operation.
>
> Two -- The road design function is much too complex to permit each project supervisor to establish his own quality standards and develop his own systems. Unless detailed guidance is provided, performance variations will be standard practice -- rather than exceptions to standard practice.

4/ The detailed network and approved project procedures resulting from this analysis are shown in the Road Design Management Manual.

Figure 3

MODEL SYSTEM

ROAD DESIGN SUMMARY FLOW CHART



Three -- Policies, procedures and standards must be developed to provide a framework within which road projects will be designed. But each project is different, and variations from the adopted framework must occur.

ORGANIZATION

The road design work systems discussed above were used as the basis for improving the organization structure of the road design function.

Existing Organization

Analyses of the existing road design organization were directed primarily toward the areas of specialization, the use of fixed-size crews and the needs for supervision.

Specialization

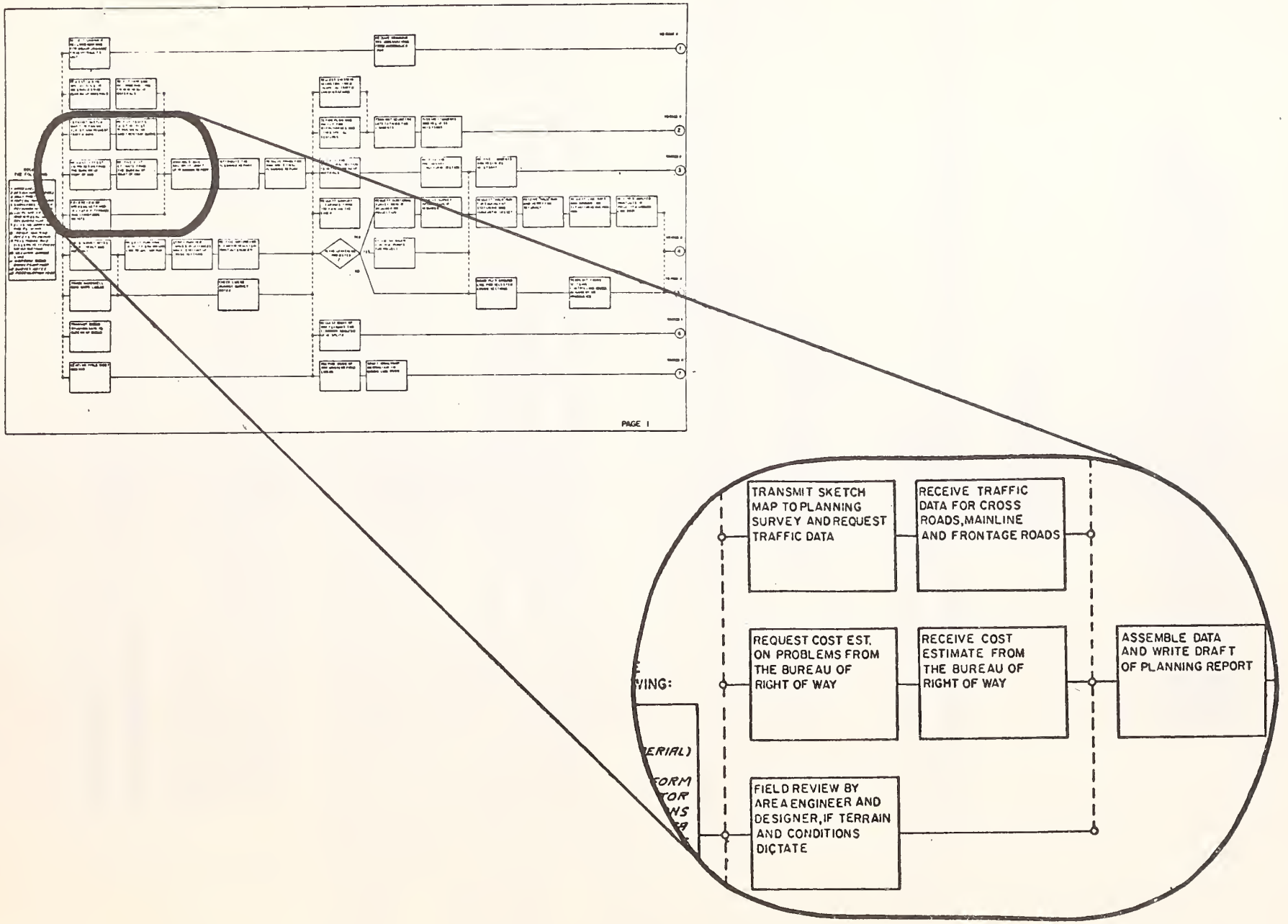
The Department relied on design specialists for many activities, including (1) landscape and beautification, (1) operational traffic engineering, (3) hydrology and (4) contract documents preparation. Crews were further specialized by highway system -- Interstate, Primary, Secondary and Urban.

Several steps were taken to identify the effects of specialization -- but the data collected are not suitable for tabulation. The findings can only be summarized. Specialization, as practiced by the Department:

1. permitted individuals and small units to advance their unique capabilities, but prevented them from expanding the varieties of their capabilities.
2. complicated greatly the problems of work scheduling, status evaluation and production control.

Figure 4

AN EXAMPLE OF DETAILED NETWORK


PAGE 1
TRANSMIT SKETCH MAP TO PLANNING SURVEY AND REQUEST TRAFFIC DATA
RECEIVE TRAFFIC DATA FOR CROSS ROADS, MAINLINE AND FRONTAGE ROADS
REQUEST COST EST. ON PROBLEMS FROM THE BUREAU OF RIGHT OF WAY
RECEIVE COST ESTIMATE FROM THE BUREAU OF RIGHT OF WAY
ASSEMBLE DATA AND WRITE DRAFT OF PLANNING REPORT
FIELD REVIEW BY AREA ENGINEER AND DESIGNER, IF TERRAIN AND CONDITIONS DICTATE

3. reduced, to almost non-existence, the ability of management officials to identify persons and units responsible for missed completion dates.

4. reduced training needs -- in that individuals did not need to be able to perform wide varieties of work.

5. reduced job satisfactions -- in that restraints were placed on capabilities development and on the opportunities for promotion.

Fixed-Size Design Crews

Montana historically has used two- or three-man design crews, with occasional variations.

The work sampling data clearly demonstrated that manpower utilization varies widely with fixed-size crews. Utilization rates dropped to 40 percent and even 25 percent at times -- due primarily to work scheduling difficulties.

Certain activities, such as plotting topography, can best be done by lower-level technicians, while the preparation of reports can best be done by project supervisors. Several activities can usually be underway at one time, but rarely can the activities be balanced to equal the manpower available in a fixed crew.

The only way fixed crew personnel can effectively be utilized is to assign several projects to each project supervisor. Work can then be proceeding on some projects at all times. When this is done, priorities established by management tend to be lost -- it being easier to concentrate on the projects with the fewest problems. Also, it is difficult to keep the work under control to prevent duplication.

Levels of Supervision

The project supervisor, or lead designer, is the first-line supervisor. He is responsible for a project whether or not it currently is in his hands. He sets detailed project schedules within the framework established by upper levels of management.

But if variable-size design crews are used, a supervisory level above the project supervisor will be needed to ensure that manpower is committed as needed. Unless some system for motivating project supervisors to control design costs is introduced -- such as salary increases based on design costs -- each supervisor will seek to advance his own projects either at the expense of other project priorities or with no concern for design costs. The scope of responsibility at the first-line level is too narrow to ensure good manpower utilization without incentives.

Summary of Conclusions

Four principal conclusions were reached from the work systems and organization analyses:

One -- There is need for specialists in road design to develop operating policies, procedures and guidelines to design, for use by design units.

Two -- Specialists can effectively be used in specific, highly technical areas, such as traffic engineering and hydraulics.

Three -- Fixed-size design crews should not be used. A system of manpower planning should be developed that will enable supervisors to assign personnel based on the quantities and types of work to be performed. 5/

Four -- If variable-size design crews are used, senior supervisors should be responsible for manpower commitments.

5/ The system developed to meet this need is discussed in Chapter Four.

Recommended Organization

The value of the organizational research is in the fact that work load, work systems, scheduling and controlling data can be used as guides to organization changes. The actual organization structure worked out for Montana is of less significance, but is discussed in this section for informational purposes.

The Montana organization developed on the basis of the analyses is summarized in two major elements -- the organization structure and the position guides.

Organization Structure

The diagram in Figure 5 depicts the organization structure of the Preconstruction Division, with a detailed diagram of the Bureau of Road Design structure.

As shown in the diagram, the Bureau of Road Design consists of two major subdivisions -- the Location and Road Design Section, and the Engineering Services Section.

The Location and Road Design Section consists of three units: Internal Design, Consultant Design and Contract Plans.

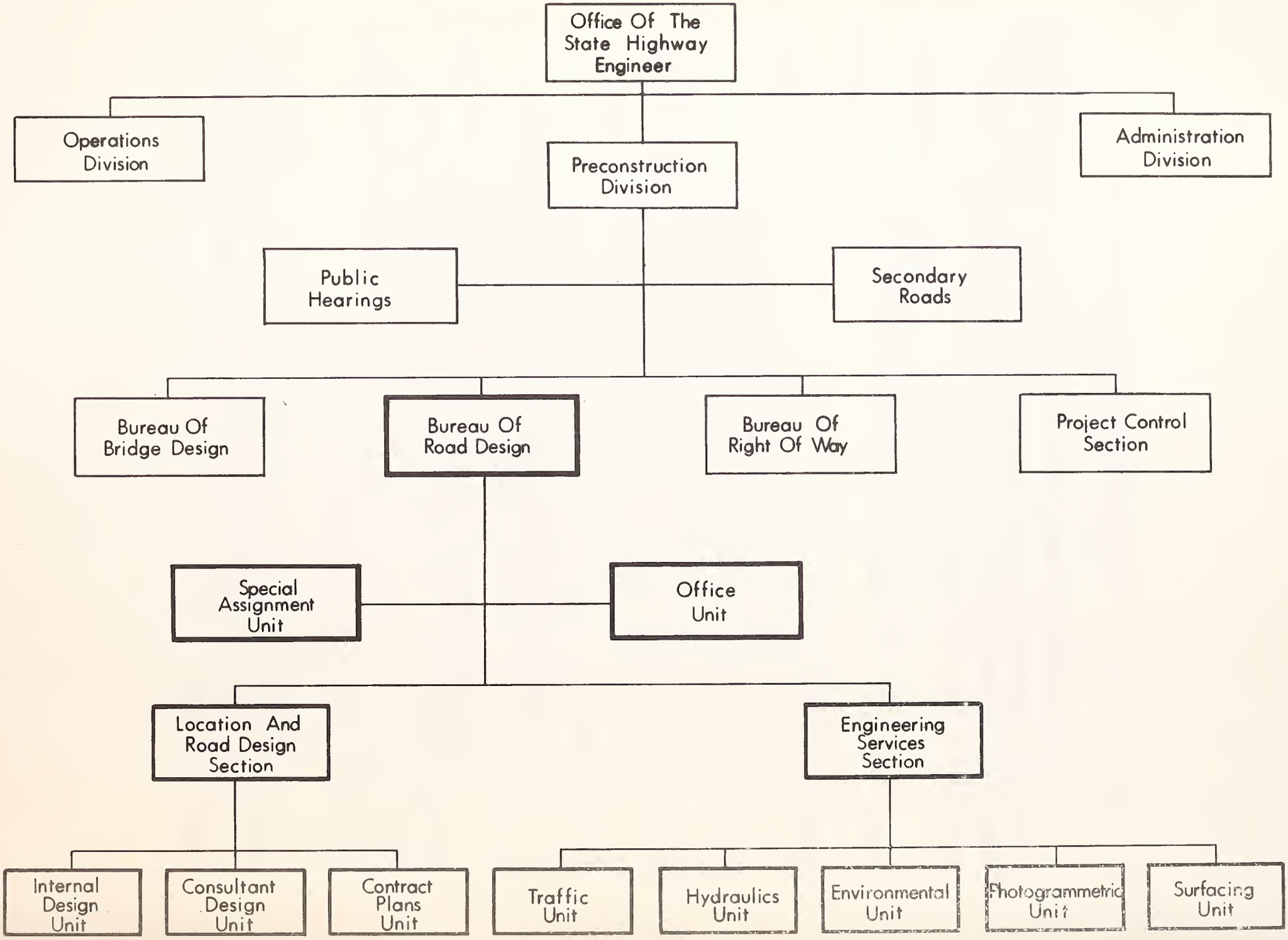
The Engineering Services Section consists of five units: Traffic, Hydraulics, Environmental, Photogrammetrics and Surfacing. These five units are defined below.

The Traffic Unit prepares plans and specifications for the fabrication and erection of signs, signals and traffic control devices; prepares operating policies, procedures, standards and specifications covering the design, manufacture and use of traffic control devices; reviews geometric design for traffic operation; and is responsible for that portion of the Highway Safety program delegated to the Department.

The Hydraulics Unit prepares operating policies and procedures; standards and specifications for drainage, irrigation structures, and special features; conducts research; and prepares plans and specifications for the design and use of specialized drainage and irrigation structures.

Figure 5

RECOMMENDED ORGANIZATION CHART



The Environmental Unit prepares operating policies and procedures; standards and specifications for the design of seeding, sodding and other roadside development; reviews environmental statements; provides guidance on the environmental effects of design; and directs and controls the preparation of landscape and beautification plans for special features.

The Photogrammetric Unit coordinates ground control; obtains aerial photographs; prepares contour maps; conducts research; and recommends the types of surveys to be undertaken.

The Surfacing Unit develops surfacing structural section design recommendations; develops special provisions and specifications for surface construction; compiles and analyzes information regarding surfacing material availability; and obtains required approvals of the structural section design.

Position Guides

Position guides define the function, responsibility, authority, and relationships of supervisory positions. Position guides were developed for the supervisors in each of the positions shown in Figure 5.[6/]

6/ Copies of the position guides are included in the reference volume.

Chapter Three

SCHEDULING AND CONTROLLING ROAD DESIGN PROJECTS

The objectives guiding the research and development of a road design scheduling and controlling system, the research findings, and the system designed for Montana are discussed in this chapter.

OBJECTIVES

This phase of the project had one objective: to design a system of scheduling and controlling so that:

- multiple project work loads can be completed within the best time-cost relationships.
- management officials can determine in advance the commitments of time and manpower needed to complete the projects.
- design managers can control the expenditures of time and manpower while work is under way.

FINDINGS AND CONCLUSIONS

The principal findings connected with scheduling and controlling work under way had to do with (1) work load size and variability, (2) work systems complexity, (3) crew size, (4) specialization, (5) communications, (6) network analysis and (7) staffing standards. Analyses of the findings led to the identification of 24 considerations that have bearing on designing systems for scheduling, evaluating and controlling road design work loads.

Work Load

As of July 1970, 154 projects were scheduled for lettings in fiscal year 1971. The design work on these projects ranged from 0 to 100 percent complete. Four to 25 projects were scheduled for letting each month.

The status of the design work on the projects to be let during the first six months is shown below:

Estimated Percentage of Completion	Number of Projects	Percent of Total
0	14	16
1 to 25	9	10
26 to 50	10	11
51 to 75	9	10
76 to 95	30	34
96 to 99	6	7
100	9	10
	87	98 7/

The total work load included several types of design projects with various degrees of complexity.

An evaluation of project scheduling and controlling requirements was undertaken by selecting two samples of projects. The first sample consisted of 39 projects -- each of

---

7/ Rounding causes the total to be less than 100.

which represented one or more miles of major construction -- scheduled for lettings during the first seven months of 1970. The second group included 25 projects actually let to contract during the first eight months of 1970. The results of this analysis are as follows:

1. Fourteen projects, about 40 percent of the 39 in the first sample, were not advertised as scheduled. Projects delayed were in all highway systems -- four Interstate, one primary and nine secondary system projects.
2. While the 14 projects were delayed, eight were accelerated and let to contract ahead of schedule. Four of these were Interstate and four were primary system projects. The period of acceleration ranged from 8 to 32 months, and averaged 15 months.
3. About 38 miles of construction were accelerated while 84 miles were delayed.
4. Twenty-five projects were let to contract in the first 8 months of 1970. Of this group, 17 were let on or ahead of the adopted schedule. The remaining 8 projects were behind schedule. The range of delay for these projects was from 1 to 5 months, for an average of two months.

The development of contract plans and preparation of contract documents requires lead time, but no fixed time requirement exists. The time required varies widely depending on (1) the resources applied (2) the class of project to be designed and (3) the characteristics of the individual project.

Evaluation of these findings led to the first three system design considerations:

1. The scheduling and controlling system must recognize the potential instability of the design program. Each manager must be informed of the status of the work under way and the impact of that status upon his responsibilities -- notwithstanding program changes.

2. The system must truly be a multiple project scheduling and controlling system -- as distinguished from a large project-by-project system with summaries. It must be capable of providing detailed data for day-to-day guidance of project supervisors and periodic summary data for top management review.

3. The system must communicate work load changes throughout the organization, in the form of revised objectives.

Work Systems

More than 240 design tasks were identified through analysis of the road design work systems. Each task has a specific place in the final basic task-sequence diagram and many are subject to complex completion interdependencies. Variations in project characteristics result in certain tasks being required by some projects, but not by others.

Evaluation of these findings led to the next three system design considerations:

4. The complexity of task interrelationships and completion dependencies are best shown with critical-path-type networks. Road design supervisors need this detailed definition to guide their day-to-day activities. But when project interdependencies are shown -- that is, when networks for more than one project are integrated -- the resulting networks become overly complex. This manner of presenting information is not satisfactory for management information systems.

5. Detailed task-sequence diagrams can be summarized into activity diagrams more suitable for project scheduling. These diagrams must show the relationships between intermediate and overall objectives.

6. The activity sequences required of projects with similar characteristics are very nearly the same. Model networks can be tailored to individual project requirements by the deletion of activities that do not apply.

Manpower Needs

The manpower needed for road design, as determined by work sampling studies and a task-by-task analysis, essentially precludes the use of fixed-size crews. Certain tasks must be completed before other work can be initiated, and the optimum mix of man-hours varies from task-to-task. Several tasks can be under way simultaneously, but the staffing needs rarely will balance if fixed-crew inputs are used.

This analysis led to the development of the next two design considerations:

7. The system must identify standard labor requirements for each task or activity.

8. The system must summarize the manpower requirements by project, time period and personnel classification.

Communications

The need for communication increases with the frequencies of changes. If programs, methods, standards, and procedures are relatively stable, communication problems become less critical. Three systems design considerations relative to communications became clear:

9. Defined objectives and project priorities must be communicated to project supervisors to ensure their attention to the "right" projects.

10. The scheduling procedures of the system should require each supervisory level to participate in program changes, insofar as those changes affect his responsibilities.

11. Paper work procedures should establish a communications link that will prohibit change unless all influenced supervisory personnel are informed.

Network Analyses

Three principal scheduling and controlling systems were reviewed as a part of this project: CPM, the Critical Path Method; PERT, the Program Evaluation and Review Technique, and the Integrated Civil Engineering System technique of scheduling and controlling. These reviews resulted in seven additional design considerations:

12. Most systems are based on network analysis -- task-sequence or work-flow diagrams.

13. Project scheduling problems for single projects are best identified through network analyses, but these analyses become overly complex when many projects are integrated.

14. Most network analyses assume fixed manpower inputs. They are oriented to crews and to expected time lapses between start and completion activities. Emphasis is given to those portions of the networks which assume the longest time periods.

15. Critical paths are more obvious in road design than many other types of project developments since the intermediate check points (milestones) require virtually all activities to each point be completed before work can proceed toward the next point.

16. Scheduling in virtually all network systems starts with the establishment of initiation and completion dates by top management. Operating managers then define objectives and detailed schedules within these dates.

17. Data processing output reports for network analyses typically are complex, using terminology not readily understood by users. This complexity is introduced in many systems through statistical projections of the probability of project completion within the time frame established. In road design, this probability, if it is to be realistic, requires an evaluation of unusual problems being encountered, resources available, the status of other projects under way, the accuracy of time estimates included in the schedule, and the status of the project in question. Usually, only the last point is considered in computer completion probability estimates. These evaluations are best made by people in positions to influence the work under way.

18. The data processing programs for some scheduling and controlling systems are so complex that their maintenance requires the services of specially trained service representatives. This is clearly undesirable. The system should be capable of being operated, maintained and revised by the persons responsible for its operation.

Staffing Standards

The definition of staffing standards enables managers to project estimated manpower requirements by project. A review of the feasibility of applying staffing standards in road design led to the six final design considerations:

19. The establishment of staffing standards is feasible if approached on a task-by-task basis.

20. Standards can be related to the best mix of employees required to perform each task if the knowledge, skill and ability requirements of each task are identified, and if each task is accorded a relative level of difficulty.

21. Work sampling, historical cost analyses and work measurement techniques can assist in the establishment of levels of difficulty requirements, but only if current systems define work by meaningful activities and if personnel classification systems are based on the work to be performed.

22. The optimum mix of personnel required to perform an activity is not greatly influenced by the type of project or the characteristics of the project being designed.

23. The numbers of man-hours required to perform certain activities are influenced by such project characteristics as length, system, culture, terrain and special features.

24. The establishment of reasonable standards is critical. But their initial accuracy is of limited importance if the system will provide for data compilation as a basis for continuing standards refinement.

Considerations Summary

Many characteristics normally associated with systems based on network analyses are most desirable and should be retained in the design of a scheduling and controlling system for road design. Primary among these characteristics are the top-level establishment of start and completion dates, the establishment of intermediate milestone objectives and the concept of network analysis itself. But many negative characteristics exist, including output reports which are unduly complicated and which attempt to make predictions beyond the capability of the data stored and data processing programming. In addition, most sophisticated projection systems are too complex to operate and maintain for a road design function.

Most network scheduling systems require the use of fixed manpower inputs -- based on subjective estimates. These systems concentrate on elapsed-time estimates and critical path evaluations. Task analyses in road design show consistent manpower requirements for each task, but varying requirements between tasks.

Specialization in project design, work-load variability and work systems complexity further complicate scheduling, and demand that decisions be communicated to the executing and working levels promptly and accurately.

SYSTEM DESIGN

The road design scheduling and controlling system designed to meet the objectives and design considerations previously set forth has three principal subdivisions. These are (1) the stage one scheduling system -- feasibility scheduling, (2) the stage two scheduling system -- detailed scheduling, and (3) the evaluation and controlling system.

Stage One - Scheduling System

The first stage of road design project scheduling requires three steps: establishment of the controlling network, definition of milestone dates and determination that the program is realistic.

Controlling Network

The summarization of related tasks into activities made the establishment of one or more model summary activity sequence diagrams feasible. Figure 6 shows the model network developed for Montana. 8/

The network guides design managers in the relationship between activities and milestones, and it is used by data processing in the development of bar chart schedules and other output reports.

Milestone Events

The summary activity network shows the chain of activities and events necessary to complete a project. The network is not time oriented, nor does it provide tangible completion objectives. These are established by project control dates -- project start and contract letting dates -- which are management's tangible expression of project priorities. Within the limits of project control dates, the executing level of the organization establishes intermediate milestone objectives.

Eleven road design milestone dates are established in Montana. Of these eleven, seven are the direct responsibility of the Bureau of Road Design.

Project Planning Milestones:

1. Complete reconnaissance studies and mapping
2. Complete project location report.

Direct Road Design Milestones:

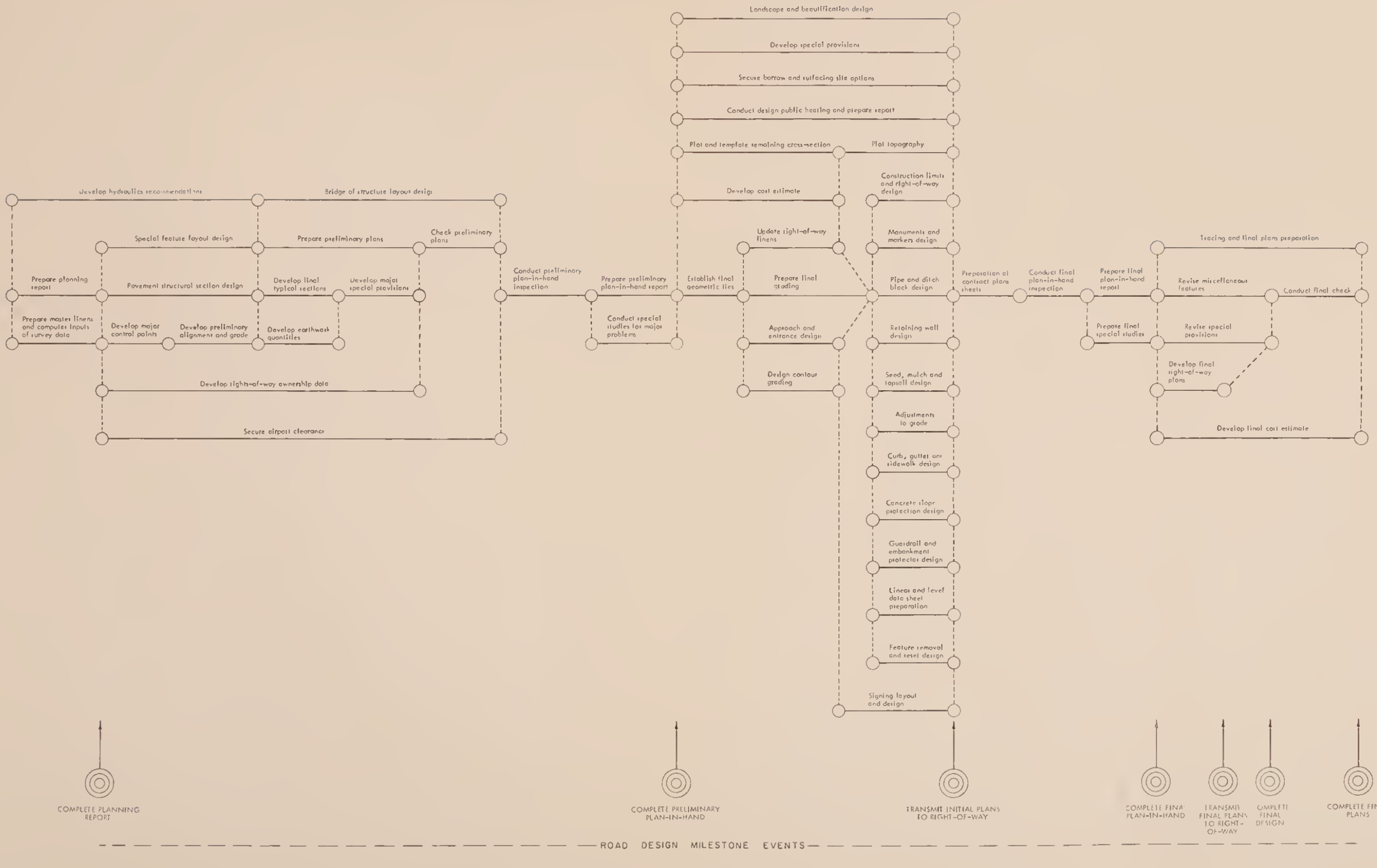
3. Complete planning report
4. Complete preliminary plan-in-hand

8/ The establishment of two model networks, one for Secondary projects and one for all other types of road design was seriously considered, but rejected in favor of simplicity.

Figure 6

ROAD DESIGN

SUMMARY ACTIVITY NETWORK


Develop hydraulics recommendations
Bridge of structure layout design
Special feature layout design
Prepare preliminary plans
Check preliminary plans
Prepare planning report
Pavement structural section design
Develop final typical sections
Develop major special provisions
Prepare master lines and computes inputs of survey data
Develop major control points
Develop preliminary alignment and grade
Develop earthwork quantities
Develop rights-of-way ownership data
Secure airport clearance
Landscape and beautification design
Develop special provisions
Secure borrow and surfacing site options
Conduct design public hearing and prepare report
Plot and template remaining cross-section
Plot topography
Develop cost estimate
Construction limits and right-of-way design
Update right-of-way linens
Monuments and markers design
Conduct preliminary plan-in-hand inspection
Prepare preliminary plan-in-hand report
Conduct special studies for major problems
Establish final geometric ties
Prepare final grading
Approach and entrance design
Design contour grading
Pipe and ditch block design
Retaining wall design
Seed, mulch and topsoil design
Preparation of contract plans sheets
Conduct final plan-in-hand inspection
Adjustments to grade
Curbs, gutter and sidewalk design
Concrete slope protection design
Guardrail and embankment protector design
Linear and level data sheet preparation
Feature removal and reset design
Signing layout and design
Tracing and final plans preparation
Prepare final plan-in-hand report
Revise miscellaneous features
Conduct final check
Prepare final special studies
Revise special provisions
Develop final right-of-way plans
Develop final cost estimate
COMPLETE PLANNING REPORT
COMPLETE PRELIMINARY PLAN-IN-HAND
TRANSMIT INITIAL PLANS TO RIGHT-OF-WAY
COMPLETE FINAL PLAN-IN-HAND
TRANSMIT FINAL PLANS TO RIGHT-OF-WAY
COMPLETE FINAL DESIGN
COMPLETE FINAL PLANS
ROAD DESIGN MILESTONE EVENTS

Note: There is no relationship between the amount of time required to perform an activity and the length of the activity line in the network.

5. Transmit initial plans to right-of-way
6. Complete final plan-in-hand
7. Transmit final plans to right-of-way
8. Complete final design
9. Complete final plans.

Preconstruction Coordinated Milestones:

10. Transmit plans to contract plans section
11. Complete field surveys.

The establishment of controlling milestone dates translates project control dates into a series of intermediate objectives. These objectives provide first- and second-level road design supervisors with specific work requirements to guide detailed project scheduling. They also provide major check points against which project progress will be measured. If problems are encountered that delay completion of milestone events, management is warned that project completions may not be attained within the time schedules established.

A standard form has been developed which communicates project control dates, milestone dates, and project responsibility assignments to data processing.

Feasibility Scheduling

Project control dates, milestone objectives, project responsibility assignments and a data processing perpetual working days calendar provide a basis for the development of a bar chart schedule. This schedule is prepared by data processing for each design crew -- the basic management unit. The elements of this report are shown below:

- Name of the project supervisor
- Project description
- Milestone event
- Scheduled milestone completion date
- Working days in period from milestone start to completion
- A bar chart showing milestone time span in months for the first three years and by quarter for the last two years of the program period.

The system is so designed that feasibility scheduling may be repeated as necessary to develop a realistic schedule. Management can alter milestone dates or project assignments without having schedules developed to see the effects of their decisions.

Stage One scheduling is repeated (1) each time it becomes apparent that milestone dates will not be met, (2) when project priorities change and revised milestone completion dates are desired, (3) once annually to coincide with budget development or review and (4) to coincide with revisions in the five-year program. Rescheduling may involve all projects or only one project.

Upon completion of Stage One scheduling the detailed scheduling required in Stage Two is undertaken.

Stage Two - Scheduling System

Stage Two scheduling requires four steps: (1) definitions of the characteristics of individual projects, (2) establishment of monthly objectives, (3) review of the resulting five-year program and (4) the determination that the proposed program is realistic as scheduled.

Project Characteristics

First-line supervisors develop a data processing input report which describes the basic characteristics of projects assigned to them. Elements of this report, which correspond with elements causing staffing standards adjustments, are as follows:

- Project number
- Road system -- Interstate, Primary, Secondary and Urban
- Adjusted road design length
- Culture and terrain
  - + Miles in rural irrigated areas
  - + Miles in mountainous or valley areas

- Special project features
  - + Number of interchanges
  - + Number of weigh stations
  - + Number of rest areas
  - + Number of major intersections
  - + Miles of frontage roads
  - + Miles of detour roads.

The data established on this report control the number and mix of man-hours planned for the completion of a project. This is done by data processing by matching project characteristics and the same characteristics in the staffing standards matrix.

Monthly Completion Objectives

First-line supervisors set monthly progress objectives that will allow them to complete their assignments within established milestone and project control dates. This is done by completing a form that has all model network activities preprinted upon it. The data included on the form are as follows:

- Project number
- Responsible project supervisor
- Work activity code and number
- The estimated percent complete each activity will be each month or quarter, as established by the first-line supervisor. Scheduled completion is estimated by month for the current year and the budget year and by quarter for the last three years in the program cycle.

The first step in completing the form is deletion of activities which do not apply. Milestone dates, which form a controlling framework around the estimator, are then plotted. The estimator evaluates the requirements of each activity, and the restraints imposed upon completion of that activity in the model network, to determine (1) the earliest activity start date, (2) the latest that the activity can be completed in order to abide with milestone dates, and (3) the estimated rate of activity completion. Once an activity is commenced, the percent completion objectives are posted for each activity until that activity is scheduled to be complete.

This report provides data processing with needed inputs to distribute scheduled manpower requirements by month. If an activity is to span three months, the manpower requirements for the activity will be distributed over the three-month period based on the projected rate of progress.

Staffing Standards

Two types of staffing standards are needed to meet project objectives. The first requires definition of the numbers of man-hours normally required to perform each of the 240 tasks identified in the project network. The second standard is needed to determine the optimum personnel classifications of the persons to be used.

Guidance in the establishment of these standards was developed by work sampling, on-site work measurement observations, detailed analyses of accounting records and finally by the review and judgment of a committee of experienced road design personnel.

1. Work Sampling -- Each task was analyzed in terms of the knowledge, skill and ability requirements and the relative level of performance difficulty. The levels of difficulty ranged from one to six, with six being the most difficult and complex.

Nearly 15,000 observations were made by trained Department observers on a random time schedule. No attempt was made to relate observations to project types. The observations were intended, for the purposes of this analysis, to provide overall guidance in the types of distributions that could be expected for the work load as a whole.

The results of the work sampling study for directly productive tasks by level of difficulty are as follows:

Level of Difficulty	Description	Percent of Observations
1	Beginning-level technician work	21%
2	Second-level technician work	12
3	Intermediate-level technician work	19
4	Senior-level technician work	11
5	Advanced-level technician work	15
6	Engineering-level work	23

2. Work Measurement -- On-site work measurement studies were conducted. The objectives of these studies were to identify tasks for which productivity measures could be established. Examples include the numbers of pages drafted, sections or pages plotted, and miles designed.

Few work activities were identified which could be related to quantifiable productivity measures. Where they were defined, they applied only to the lower levels of performance difficulty. The productivity data that were developed were summarized, and units of measure were established. Results were added to the task standards sheets along with their relative levels of difficulty.

3. Cost Records Analyses -- Detailed analyses of man-hours charged by personnel classification and project type were made -- but were largely a failure. The current reporting system is not based on useful activity definitions. Also, obvious errors exist in the reported data, and the current personnel classifications are of doubtful validity.

Data that were usable were compiled and placed on the detailed task standards sheet previously described.

4. Committee Participation -- A special committee of experienced road design personnel was formed. They were given the following assignments:

+ To develop a unit of measure and a preliminary staffing standard for each task in the task-sequence network. Their frame of reference was a five-mile Primary System project. They were given all standards data available to guide their judgment.

+ To group the tasks shown in the detailed work sequence diagram into logical combinations of tasks. This would provide a summary activity network for scheduling and controlling.

+ To identify project characteristics that would effect the validity of the standard, and to then develop an adjustment factor for those characteristics.

+ To establish the manpower mix, by personnel classification, needed to perform each activity. They were guided in this

work by the levels of difficulty originally assigned to each task and the number of man-hours accumulated by task to form the staffing standard.

The result of this work is a standards matrix. An example page of the standards developed is included in Figure 7.

Each activity has an assigned man-hours requirement, but this requirement is varied in accordance with project characteristics -- length, system, culture, terrain -- and the special features associated with the project. The standard for the preparation of master linens and computer inputs of survey data, for example, is 16 man-hours per mile. If it is an urban project, the standard is doubled. If it is in a mountainous area, the standard is increased by 25 percent. In addition, the standard defines the personnel classifications of those persons best suited to perform the activity. In the example, the standard indicates that intermediate-level technicians -- Technicians II and Technicians III -- should prepare master linens and computer inputs. Further, the total man-hours allowance is equally distributed between the two classifications.

Plan and Budget

The culmination of Stage One and Stage Two scheduling is a five-year road design manpower plan and budget report. This is the first report in the system which converts man-hours to costs. This conversion is accomplished by data processing using standard labor costs by personnel classification.

The primary elements of this report are listings of the following items by road design project:

- The estimated total man-years and costs required to complete each project.
- The man-years and costs attributable to each project through the end of the last fiscal year.
- The estimated man-years and funds needed for each of the coming five years in the approved program.

Figure 7

AN EXAMPLE OF MANPOWER STAFFING STANDARDS BY ACTIVITY PROJECT CHARACTERISTICS AND PERSONNEL CLASSIFICATION

ITEM ↓ / WORK ACTIVITY DEFINITION →	Prepare Preliminary Plans	Check Preliminary Plans	Conduct Preliminary Plan-In-Hand Inspection	Prepare Preliminary Plan-In-Hand Report	Conduct Special Studies for Major Problems	Landscape and Beautification Design	Develop Special Provisions	Develop Cost Estimate	Plot and Template Remaining Cross Sections	Secure Borrow and Surfacing Site Options	Establish Final Geometric Ties	Approach and Entrance Design	Prepare Final Grading
UNIT OF MEASURE	Mile	Mile	Project	Project	Project	Project	Project	Mile	Mile	Project	Feature	Mile	Mile
MAN-HOURS PER UNIT	7.0	5.0	34.5	12.0	14.0	4.0	8.5	3.1	24.0	6.0	25.0	13.0	7.2
ADJUSTMENTS:													
Interstate	100%	100%	125%	100%	400%	100%	200%	200%	150%	100%	—	—	100%
Primary	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	—	100%	100%
Secondary	100%	100%	75%	100%	100%	—	100%	67%	100%	100%	—	200%	100%
Urban	120%	100%	100%	100%	200%	100%	100%	100%	150%	100%	—	100%	100%
Irrigated	—	—	20%	—	100%	—	50%	33%	20%	—	—	—	—
Mountainous	—	—	25%	—	50%	—	50%	33%	50%	—	—	—	—
Unit of Measure for Special Features	None	None	None	None	Feature	None	Feature	Mile	Feature	None	Feature	Mile	Mile
Interchanges	—	—	—	—	—	—	—	—	150%	—	100%	—	—
Weigh Stations	—	—	—	—	100%	—	50%	—	100%	—	100%	—	—
Rest Areas	—	—	—	—	100%	—	50%	—	100%	—	150%	—	—
Major Intersections	—	—	—	—	100%	—	50%	—	100%	—	50%	—	—
Frontage Roads	—	—	—	—	—	—	—	50%	—	—	—	100%	50%
Detour Roads	—	—	—	—	—	—	—	50%	—	—	—	—	50%
DISTRIBUTION BY PERSONNEL CLASSIFICATION													
Technician I	—	—	—	—	—	—	—	—	—	—	—	—	14%
Technician II	27%	—	—	—	—	—	—	—	67%	—	—	—	56%
Technician III	—	—	—	—	—	—	—	52%	33%	100%	—	38%	—
Senior Technician	2%	20%	—	—	—	—	—	—	—	—	100%	62%	30%
Project Supervision	71%	80%	100%	100%	100%	100%	100%	48%	—	—	—	—	—

Note: Total manpower requirements for an activity are cumulated by the characteristics of the project. The standard for conducting preliminary plan-in-hand inspections is 34.5 man-hours per project but this is increased to 43.1 hours for Interstate (125% x 34.5 hours). If adjustments other than system are required the total adjustment percent is accumulated. In the example irrigated Interstate is 125% + 20% = 145% times 34.5 hours or an adjusted standard of 50 hours per project.

- A recapitulation of the man-year requirements by personnel classification for each of the five years in the program cycle.

This report permits management to review the road design work load in terms of resource requirements. It also provides them with guidance in deciding whether to increase or reduce manpower in upcoming years, use consultants for design projects, or change the control dates.

The manpower utilization ramifications of each decision can be simulated by repeating the Stage One and Stage Two scheduling.

Evaluation and Control

Progress evaluations and control are established through two manual input reports -- a weekly time sheet and a status report -- from which five data processing reports are prepared. 9/ The five reports cover (1) the status of road design, which is an output-input report, (2) a summary status report, (3) a missed milestone report, (4) a manpower control report and (5) a budget analysis report.

Weekly Time Sheet

Each employee prepares a weekly time sheet. Elements shown on this report are:

- The projects worked on during the reporting period.
- The activities accomplished, as defined in the model activity network.
- The man-hours charged to each activity and project.

Status-of-Road-Design Report

The status-of-design report is a data processing output record and a status-of-design input report. One report is prepared for each active project. The format of this report is shown below:

9/ A third report describing the status of field surveys is used in Montana.

SCHEDULED AND ACTUAL PROGRESS						
	January		February		March	
Activity	Schedule	Actual	Schedule	Actual	Schedule	Actual
Prepare Final Grading	10%		15%		25%	

Data processing completes the scheduled portion of the report quarterly and transmits the original and three copies to the project supervisor. At the close of the first month, January in the example, the supervisor records his actual progress and submits the report for review and transmittal to data processing. At the end of February and March, the supervisor repeats the process on the first and second carbon copies of the report form.

This procedure permits the following:

- Timely reinforcements of the supervisor's objectives.
- Records of progress and status.
- Early detection of non-performance.
- A way to have data processing take much of the paper work out of progress reporting.

These reports and the weekly time sheets provide project status inputs for the evaluating and controlling portion of the system.

Summary Status Report

The summary status report describes project progress by comparing planned and actual milestone accomplishments. The report has four major elements: project identification, status of completed milestones, status of active milestones and future milestone dates.

The project identification section of the report describes the general characteristics of the project -- project number, type, length and location, the senior supervisor responsible for its completion and the scheduled contract date. The report is organized by contract letting date. The first project to be let is listed first.

1. The completed milestone section shows the dates milestones were scheduled for completion and the date work actually was completed.

2. The active milestone section shows the date each milestone is scheduled for completion, the percentage of completed work and the working days remaining before the scheduled completion date.

3. The future milestone section shows the date up-coming milestones are scheduled for completion.

Missed-Milestone Report

The missed-milestone report is a monthly "exception" report. Only milestone events scheduled for completion but not completed are reported.

Manpower Control Report

The manpower control report is a project-by-project listing of (1) the estimated total man-hours required to complete active projects, (2) the man-hours used to date, (3) comparisons of planned and actual manpower usages, and (4) the numbers of man-hours that will be required each month in the up-coming six-month period. The data are summarized by personnel classification.

Budget Analysis Report

Data in the budget analysis report are organized by personnel classification and include (1) the fiscal-year budget by man-months and dollars, (2) the total man-months expended to date, (3) the percentage of budgeted man-hours used, (4) the estimated man-months needed during the balance of the fiscal year, (5) conversions of the needed man-hours to numbers of employees and (6) a revised estimate of man-months and dollars needed to complete the fiscal year program.

Standards Refinement

The final report in the system is a staffing standards adjustment report. It is prepared by data processing once annually, but can be requested at any time. It includes two items of data for each activity:

- The current staffing standard value, the adjustments applied to that standard to reflect the project characteristics, and the current standard distribution by personnel classification.
- The actual man-hours spent on the activity and the actual distribution of man-hours used by personnel classification.

SUMMARY

Three principal elements make up the scheduling, evaluating and controlling system: (1) feasibility scheduling, (2) detailed scheduling and (3) evaluating and controlling. The interrelationships of these elements are shown in Figure 8.

Feasibility Scheduling

Feasibility scheduling is based on project control dates shown in the approved five-year program. Design managers establish intermediate milestone objectives within the control dates. Using these data, and a perpetual-working-days calendar, data processing prepares a bar chart schedule for each responsible management unit and project. After a general work load review and management approval, detailed project scheduling is initiated.

Detailed Scheduling

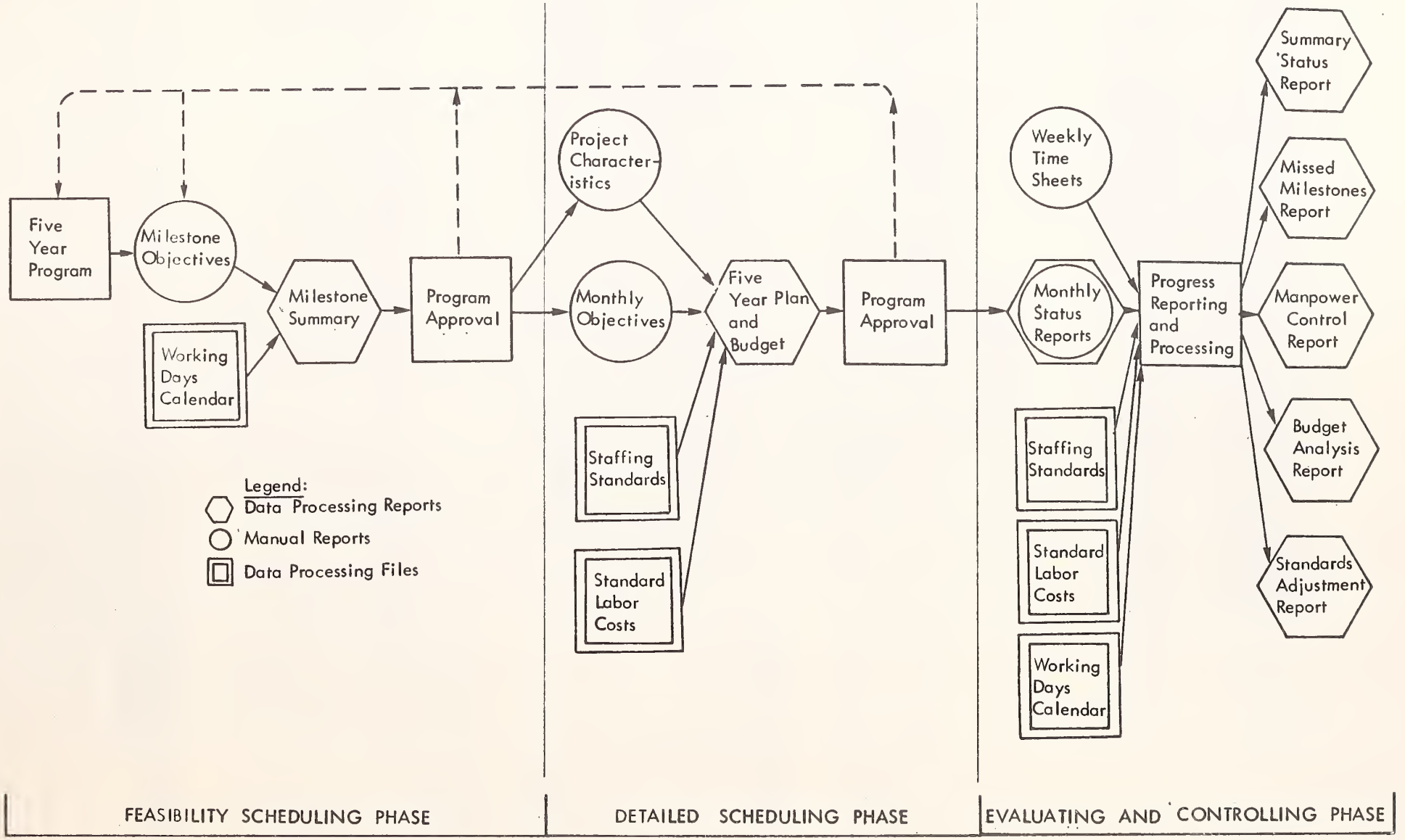
First-line supervisors establish month-by-month objectives within the limits imposed by the milestone objectives and prepare a report showing the characteristics of each project. Using these data, together with staffing standards and standard labor costs, data processing develops a five-year manpower plan and budget. Approval of this plan provides the designers with execution authority.

Evaluation and Control

Data processing preprints monthly status reports. Road designers report their actual activity-by-activity progress and submit monthly reports to data processing. These reports, together with weekly time sheets, staffing standards, standard labor costs and a working-days calendar, provide the inputs for developing control reports: progress, status, resources used and milestones missed.

Figure 8

SCHEDULING AND CONTROLLING SYSTEM SUMMARY WORK FLOW



Chapter Four

PERSONNEL CLASSIFICATION AND SALARY PLANS

The two basic instruments of personnel management are the classification plan and the salary management plan.

PERSONNEL CLASSIFICATION

Two Types

Most government agencies classify positions exclusively--without regard to the employees who occupy those positions. But employees can be classified, often to the advantage of both the employer and the employee.

Position classification plans should be used whenever the numbers of persons employed will not change regardless of employee performance. The chief design engineer position should be classified, for example, since one employee always will be needed.

Employee classification plans should be used whenever the numbers of employees needed will decrease as the productivity levels of those employed increases. Design technicians should be classified, for example, since the more work the individuals can produce, the smaller the number of technicians employed can be.

Purposes

Personnel classification plans have four principal purposes, two of which are not always recognized by classification specialists:

1. to ensure equity in administering salary plans.
2. to provide bases for recruiting, screening and selecting personnel.
3. to provide bases for manpower planning and management.
4. to provide bases for developing and recognizing individual capabilities.

The first two purposes above can be served by position classification plans. The third and fourth purposes can best be served, in most cases, by employee classification plans.

Department Plan

The Department's personnel classification plan included 38 classification titles to cover above 150 positions in the Preconstruction Division--or four positions per title. No employees were classified.

Plan Effectiveness

The work sampling data provided clear indications of the effectiveness of the original technician classification plan.

Figure 9 shows the average level of difficulty of the work performed by personnel employed in eight technician classifications. As the data show:

1. No significant difference exists in the work performed by Draftsmen II and Draftsmen III, or by Designers I and Designers II.
2. No reason exists for creating more than five, preferably four, classifications.

Since only four engineers were employed within the road design function, and since three of these persons had non-design responsibilities as well, the effectiveness of the engineering classification plan could not be determined. It may be that additional engineers would have been employed under a different personnel classification system, but no data are available that indicate one way or another on that point.

Figure 9

ANALYSIS OF THE EFFECTIVENESS

OF THE EXISTING PERSONNEL CLASSIFICATION PLAN

Personnel Classification	Average Level of Work Difficulty
Draftsman 1	1.
Draftsman 11	2.3
Draftsman 111	2.2
Detailer 1	3.5
Detailer 11	2.8
Designer 1	3.9
Designer 11	4.1
Designer 111	4.5

Proposed Classification Plan

As indicated above, classification plans can, among other things, be used to reduce manpower needs.

Manpower Utilization

More than 240 tasks were identified in connection with the road design function, such as plotting cross-sections, computing areas, plotting mass diagrams and plotting construction limits. The individual tasks are not available for performance day after day--but only as the need for their performance occurs during the course of each project. As a result, five manpower utilization assumptions can logically be made:

1. Design engineers, under pressure to complete projects, will assign the work to the persons available for doing it and capable of doing it.
2. Designers will, within the limits of the work immediately to be done, assign the difficult tasks to advanced-capability personnel and simpler tasks to the less capable personnel.
3. The wider the variety of the tasks an individual can perform, the more consistently will he be given useful work to do, and the more valuable will he be to the design function.
4. Since the work must be done as it comes up, advanced personnel must, at times, perform simple tasks--or perform no work at all until the simple tasks have been completed.
5. The total manpower needs can be reduced by (1) advancing the capabilities of all personnel and (2) ensuring that all personnel are engaged in the performance of needed work.

Motivation

Research in industry has demonstrated that employees are motivated by, among other things:

1. having enough work to do
2. having useful work to do
3. using clearly effective work methods
4. using their performance capabilities to good advantage
5. advancing their performance capabilities
6. being recognized by performance.

Type of Plan

The five manpower utilization factors and the six motivation factors can be made to support each other through an employee-but not through a position--classification plan.

An employee classification plan can be based on performance capability--meaning the wider the variety and the greater the depth of the tasks that can be performed, the higher the classification can be. Promotions can be granted as earned. And the total number of persons employed can, through attrition, be reduced as the percentages of employees in advanced classification are increased.

Position classification plans are less flexible than employee classification systems. Only the level of difficulty of the assigned work is measured, not the quality, quantity or variety. Performance improvements might be recognized through salary increases, but not through reclassifications.

Proposed Technician Classifications

The activities performed by road design technician personnel are tabulated in Figure 10. Each activitiy has been assigned, by a committee of engineers and technicians, to a level of performance difficulty.

According to the proposed technician classification plan, the employees will be classified as:

Technician I on entrance to employment.

Figure 10

TECHNICIAN PERSONNEL CLASSIFICATION PLAN

ROAD DESIGN ACTIVITIES

BY LEVELS OF DIFFICULTY

LEVEL ONE

- Inking and tracing
- Plot construction limits
- Prepare ROW linens
- Plot cross-sections
- Compute areas
- Plot mass diagrams

LEVEL TWO

- Plot survey data
- Computer grade lines
- Plot drainage
- Prepare displays and illustrations
- Compute earthwork
- Code basic computer inputs
- Extend estimates and quantities
- Prepare utility plans
- Determine theoretical crush-down
- Develop standard city agreements
- Prepare bid summaries

LEVEL THREE

- Check notes preparatory to plotting
- Template cross-sections
- Design clearing and grubbing
- Compute ROW areas of taking
- Compute final quantities
- Cross-check road and bridge plans
- Prepare ROW sepias
- Review consultant agreements
- Prepare engineer's estimate
- Prepare proposal package
- Prepare for letting
- Conduct letting and evaluate bids

LEVEL FOUR

- Design contour grading
- Design miscellaneous features
- Design fencing
- Check and interpret computer runs
- Design ROW limits
- Determine soil support values
- Prepare modified estimate
- Compile and review standard drawings

LEVEL FIVE

- Interpret and plot property lines
- Check and review plans
- Design structural sections
- Select materials sources
- Develop contract bid item list
- Develop special city agreements
- Write final special provisions
- Present project to Board of Review
- Prepare reports
- Design typical sections
- Design alignment and grade
- Design intersections, interchanges, etc.
- Design drainage
- Prepare preliminary estimates
- Write preliminary special provisions
- Code complex computer inputs

Technicians II when they demonstrate ability to perform all Level One activities, plus two Level II or Level Three activities.

Technicians III when they demonstrate ability to perform all Level One and Two activities, plus three activities in the Level Three or Four categories.

Senior Technician upon demonstration of two capabilities: (1) ability to carry out the One, Two and Three Level activities, plus four activities from Four or Five, and (2) ability to supervise personnel in preparing contract plans for road projects.

Project Manager upon assumption of responsibility for completing road design projects.

Senior Manager upon assumption of responsibility for several project managers.

The project manager and senior manager classifications are sub-professional counterparts to the project engineer and senior engineer classifications defined below.

Technician Advancements

The technician personnel can advance to the senior technician level by proving they can do the work. They can advance to the project and senior manager classifications essentially the same way since the numbers of persons needed in those classifications are likely to exceed the numbers qualified for several years.

Self-Operating Plan

The technician personnel should always be working "in classification"--as distinguished from the practice with the existing plan. They will be classified according to demonstrated performance capabilities, not according to the specific tasks that make up their work loads at certain points in time. They will perform the work as it comes along, with the advanced personnel receiving the most difficult assignments--in response to the needs of the project managers to meet deadlines. But they will also perform whatever work needs to be done, including the simplest assignments at times, thereby reducing the overall need for manpower.

Engineering Classifications

The proposed engineering classification plan is based, principally, on the position classification concept.

The Engineer classification will cover beginning-or-engineer-in-training-level persons.

The Project Engineer classification covers positions or persons responsible for completing design projects in accordance with plans, schedules, budgets and defined policies and procedures.

Senior Engineers will supervise project engineers, making such changes in plans, schedules, budgets and staffing as are needed to advance the work of a number of projects for the Department.

An Executive Engineer will be responsible for carrying out the adopted road design program on a day-to-day basis.

An Administrative Engineer will be responsible for defining the work program for inter-divisional relationships, and for long-range functional improvements.

Engineering Advancements

The characteristics of position classification plans apply--there being need for a vacancy before an advancement can be made.

SALARIES

General Salary Levels

Salary Survey

A survey was conducted to identify how well the Department meets the competition in terms of salaries

The salaries paid by fully competitive employers--firms and agencies able to recruit and retain persons needed by the Department from the labor markets used by the Department--were identified. Each in-state employer contact was made through a personal visit to ensure that all salary data, including overtime and bonus payments, were obtained and that the persons or positions being compared were fully comparable. Out-of-state employer data were collected by questionnaire.

Competitive Standing

The survey results, as they apply to the road design function, are tabulated in Figure 11.

As can be seen, the Department pays reasonably competitive salaries to engineers-in-training. But, when the graduate engineers have completed their first years of experience, they can increase their salaries by an average of 35 percent by leaving Department employment. If they stay with the Department until they reach the senior level--with responsibility for carrying out a series of project simultaneously, they will receive 24 percent less than they would with other employers.

The executive engineer classification was not included among the key-classifications surveyed, but the administrative level was--revealing a 16 percent adverse differential.

While most engineers are underpaid, the survey data show that many technicians are overpaid. The average salaries of the second- and third- level sub-professionals are 9 and 13 percent above those paid by other successful employers. The first - and fourth - level technicians are receiving essentially prevailing rates, while the project supervisors are 12 percent underpaid.

Plan Characteristics

One principal objective of this project was to bring manpower needs and manpower complements into balance. It cannot be done, of course, with a non-competitive salary plan and a Department plan which does not promote incentive as well.

Figure 11

COMPARISON OF DEPARTMENT SALARIES
TO PREVAILING RATES

December 1970

	Department Average	Prevailing Average	DEVIATION FROM PREVAILING RATE Amount	Percent
ENGINEERS:				
Engineer-in-training	$ 8,800	$ 9,100	- $ 300	- 3
Project Engineer	9,500	14,600	- 5,100	-35
Senior Engineer	12,200	16,100	- 3,900	-24
Administrative Engineer	18,800	22,300	- 3,500	-16
TECHNICIANS:				
First-Level Technician	$ 6,000	$ 6,000	--	--
Second-Level Technician	7,500	6,840	+ $ 660	+ 9
Third-Level Technician	8,880	7,800	+ 1,080	+13
Fourth-Level Technician	9,660	9,840	- 180	- 2
Project Supervisor (non-engineer)	10,680	12,120	- 1,440	-12

Non-Competitive

The existing salary plan has been shown to be non-competitive through the salary survey data.

More than that, the existing plan would be difficult to convert into a truly competitive plan. It consists of 21 pay ranges, with each range being a fixed percentage greater than the one below. Each range is sub-divided into steps, with each step being a fixed percentage greater than the one below.

The grid-system would seem to provide the basis for a fair and equitable system. Yet, it does not. When prevailing ranges must be adjusted to fit the fixed ranges set forth in salary grids, employee groups gain or lose according to the "fits" that can be worked out. And when attempts are made to create internal relationships that are more equitable than those found in the labor markets, overpayments and underpayments--and unnecessary turnover rates--must occur.

If all personnel were paid within the prevailing salary ranges existing for their classifications in the labor markets in which they are employed, equity would exist. Internal equity would also exist.

Prevailing rate plans may not result in uniform grids. But they do result in paying the labor costs that must be paid, and no more than those costs.

Non-Incentive

One-step salary increases are granted annually, unless an unusual behavior or performance problem exists. Uniform across-the-board percentage increases are granted from time to time as cost-of-living adjustments.

No measurements of performance are made, and no defined opportunities exist for relating cost reduction or increased production to salary increases.

Analysis

The Department must operate within restraints placed upon it by the Legislature and

by central personnel and budget control agencies. Even so, analysis of the data discussed in this and previous chapters indicates the following:

1. If prevailing rates had been known to the Department during the last several years, and if that percentage of prevailing rates that could have been paid within budgeted funds had been paid, no employee classification would be seriously below the market salary levels. Some employees are seriously being underpaid because other employees are being overpaid.

2. If non-essential work loads had been eliminated, and if effective management systems had been developed, the manpower needs would have been reduced--and fully competitive salaries could have been paid within current appropriations.[10/]

3. The salary plan and the salary increase practices should work to the advantage of the Department:

   - Prevailing rates should be paid to ensure continuous employment of competent personnel.
   - Performance should be recognized--through appropriate and timely salary increases.
   - Non-performance and inadequate performance should also be recognized--through salary increase denials.

Proposed Plans

One salary plan, based on annual rates, was developed for the engineers. Another, based on monthly rates, was developed for the technicians.

Each plan includes a range of salaries for each classification, based on the prevailing ranges. The ranges are not divided into steps.

10/ This, obviously, means that manpower complements should be reduced. And they should be. The needed reductions can, obviously, be accomplished without dismissals or layoffs.

Engineering Plan

The engineering salary plan is shown in Figure 12.

The classifications titled Engineer, Project Engineer, Senior Engineer and Administrative Engineer were used as key classifications in conducting the salary survey. The prevailing ranges found for those classes were used to establish the respective ranges shown in the proposed plan. The remaining salary ranges were established in relation to the key classifications.

As indicated in Figure 12, all annual salaries have been rounded to the nearest $100. No salary levels such as $11,009 or $15,141 are available--though such salary levels are typical of grid plans.

Technician Plan

The proposed technician salary plan is shown in Figure 13.

All classifications except Senior Manager were included as key classifications in the salary survey. All ranges shown for the key classifications are those found to prevail among successful competitive employers, rounded to the nearest $25.

Implementation

A trial-run implementation effort was completed, using a sample group of personnel.

Evaluations

The 134 employees included in the trial run were evaluated primarily on direct-performance factors, first by their immediate supervisors and then by all supervisory personnel in positions of knowledge sufficient to make such evaluations.

The direct-performance factors included (1) productivity rates, (2) quality levels, (3) potential for advancement, and (4) current and projected work assignments.

Some consideration was given to age, education, experience and attitude factors.

Figure 12

MONTANA DEPARTMENT OF HIGHWAYS
ENGINEER SALARY PLAN
JUNE 1971

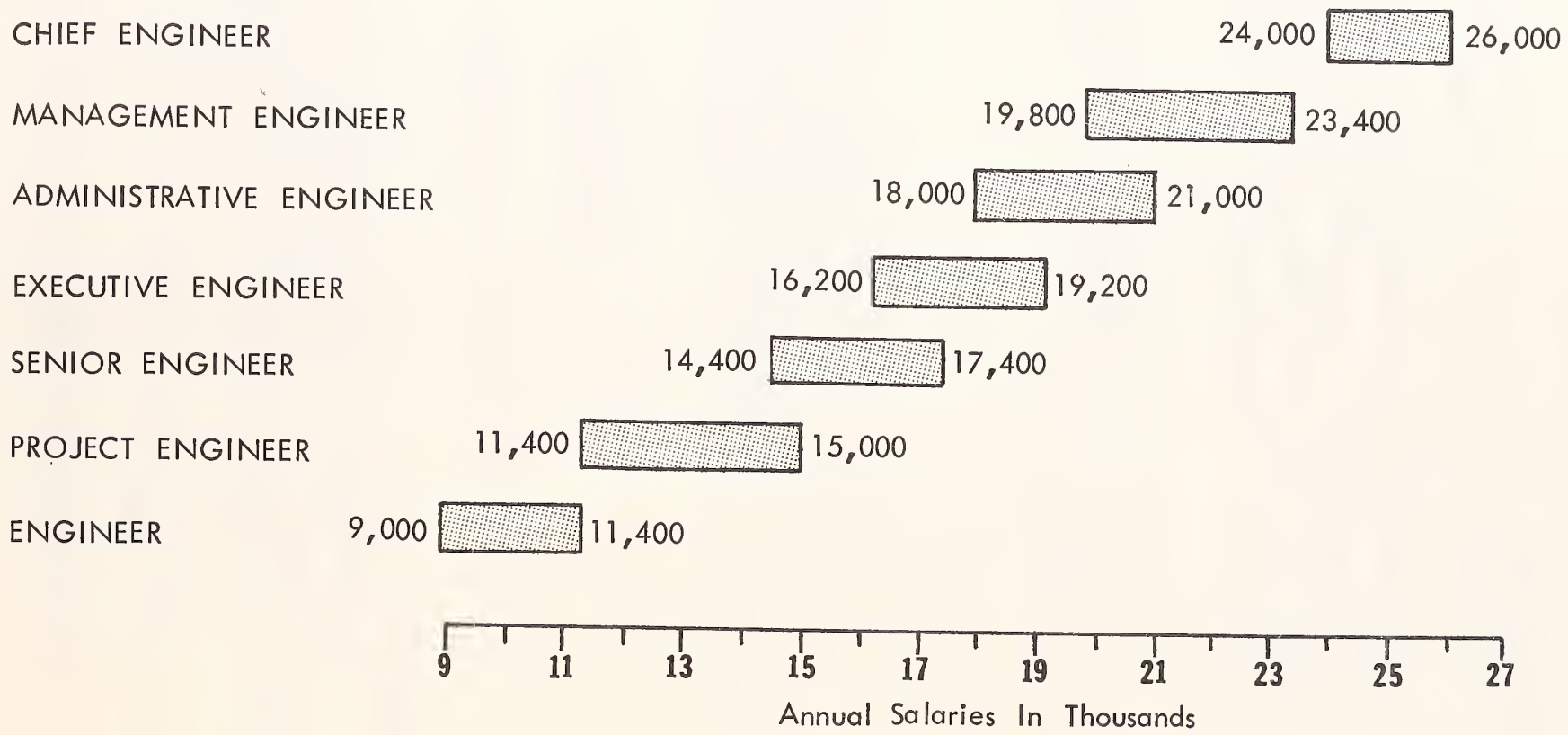
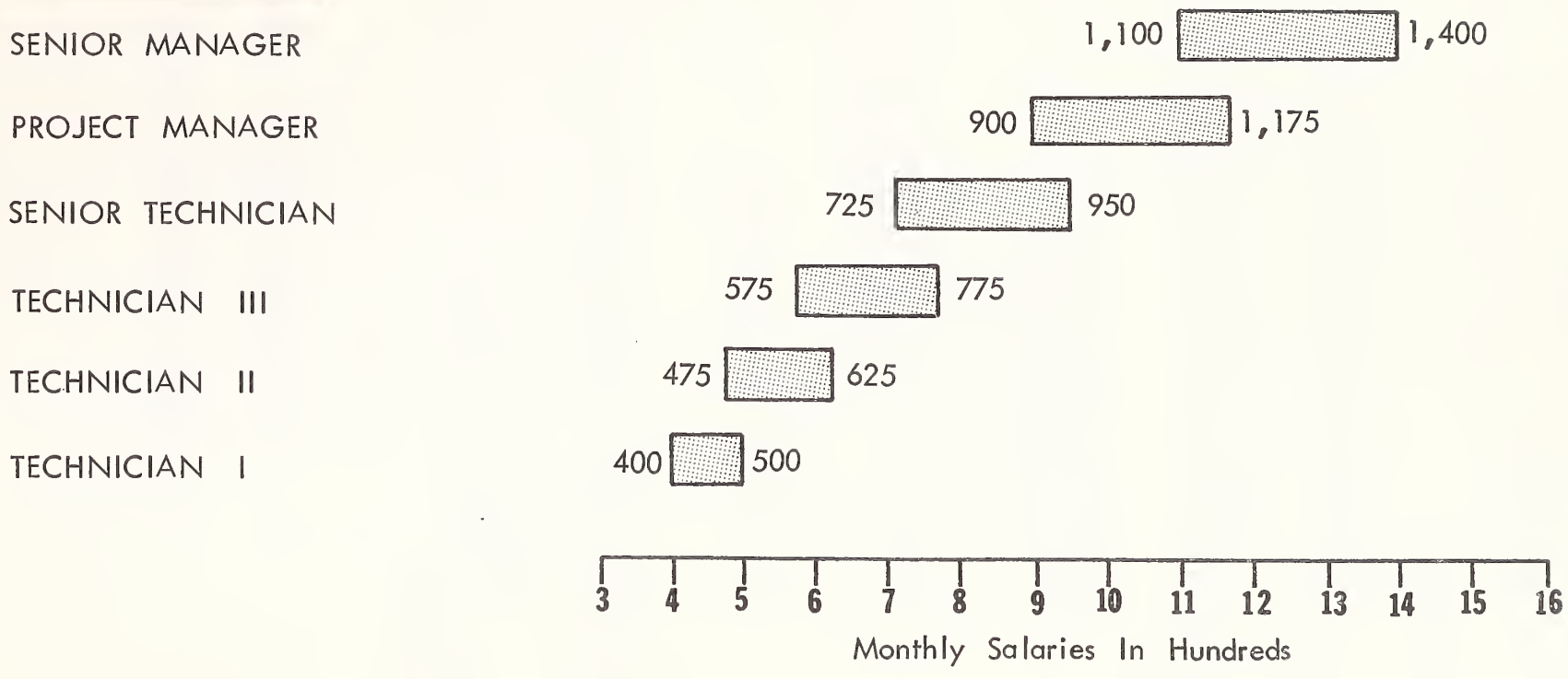


Figure 13

MONTANA DEPARTMENT OF HIGHWAYS
TECHNICIAN SALARY PLAN
JUNE 1971



Obviously, any serious attendance or behavior characteristics were reflected in the direct-performance values.

Comparisons

The Legislature appropriated funds for an 8 percent salary increase. The Department had the option to grant 8 percent across-the-board increases or to grant incentive increases.

A comparison of potential across-the-board increases with incentive increases indicated that across-the-board increases would make the situation more difficult than it already was.

INCREASES THAT SHOULD BE GRANTED--ON BASIS OF PERFORMANCE	EVALUATED EMPLOYEES	
	NUMBER	PERCENT
1. No increases--now overpaid	23	17
2. Increases of less than 8 percent	35	26
3. 8 percent only	7	5
4. Increases above 8 percent	69	52
	134	100

Had 8 percent across-the-board increases been granted, 43 percent of the employees would have been overpaid while 52 percent continued to be underpaid.

Implementation of the prevailing rate salary plans, without offsetting manpower reductions, will increase the total payroll cost by 13 percent. This assumes adherence to the following policies:

1. No salaries will be reduced.
2. No employees, other than seasonals, will be terminated, laid off or caused to resign.
3. Salary increases will be granted on the basis of actual performance values.

Procedure

The plans can be implemented within current appropriations if the following policies are adopted:

- Employees who leave the service will not be replaced, except through promotions.
- Savings will be used to finance salary increases for the remaining employees.
- Salary increases will be granted in stages--as the finances become available.

The recommended system has not yet been implemented, however, the study has been expanded to cover the remainder of the Department personnel.

Chapter Five

TRAINING

The principal elements of a training needs survey are (1) an inventory of the manpower currently employed, (2) an estimate of the manpower to be employed, (3) identification of the potential training needs, and (4) identification of the actual training needs. These elements are discussed first below.

The principal elements involved in developing a plan for training are (1) identification of the alternative methods of training, (2) determination of the subject matter to be covered, and (3) analysis of the potential costs of each method. These elements are discussed in the second section below.

A general plan for training the Montana road design personnel is discussed in the final section.

NEEDS SURVEY

A formal training needs survey was completed as a part of this project.

Current Manpower

The size of an employee force, the geographical locations of the employees, the variations in age, education and experience levels, and the variations in their potential capabilities for learning all have bearing on the design of a training program.

Size and Location

The size of a force and its geographical distribution have much to do with the selection of training approaches -- the method of training being dependent to a great extent on both factors. Classroom and workshop methods typically are expensive, on a per-employee basis, if large numbers of persons are to be trained, and particularly if travel expenses will be involved. Self-instructional courses are expensive to develop, on a per-employee basis, if the numbers of employees are small -- less than 100, for example -- and particularly if such a relatively small force is located in one city.

Eighty-one persons are employed in the road design function. Seventy-five of those persons are employed at the headquarters office in Helena, and six in the district offices.

Age Variations

If the employees potentially to be trained are all in one age group, they can reasonably be treated alike, from that standpoint at least. They all will have left the public schools at about the same period in time, and will have reasonably the same attitudes toward classroom techniques. If not, self-instructional approaches have been shown, in many industries and through some government agencies, to overcome many of the difficulties attributable to age differences.

The 81 road design employees range in age from 20 to 65 years.

Education

Variations in education levels increase the difficulties connected with training. Even when persons with limited educations can learn to do the work more rapidly than those with a few additional years of formal education, consideration had best be given to the differences.

Seventy-seven of the 81 road design personnel are high school graduates, and 49 have completed one or more years of college. These data indicate that essentially three education levels exist, of which the lowest is limited to four persons.

Experience

Variations in experience levels have significant bearing on the approaches to be used in training. Persons with limited experience must yet learn even the terminology unique to the work assignments. And persons with extensive experience may find it difficult to accept new work methods. Further, persons with considerable experience, while they need the training, typically find it difficult to wait while new personnel are learning the basics.

The experience levels of the 81 employees range from less than one year to more than 25 years.

Capacities To Learn

Differences in the abilities of employees to learn from training present the most difficult problems. Learning skills are directly related to reading, writing and calculating capabilities, and to reasoning capacities.

The Wonderlic Personnel Test -- the most generally accepted learning capability test on the market -- was administered to a sample group of road design employees to obtain indications of the potential learning capabilities of all the road design personnel. The test contains 50 questions covering reading skills, relationships of numbers, logic, and elementary geometry. The number of questions answered correctly in 12 minutes indicates, within reasonable limits of validity and reliability, the ability of an individual to master technical subject matter. The variations in learning capabilities are of greatest significance from a training program design standpoint -- there being need to ensure that language levels, sentence structures and presentations are used that permit persons with different learning capabilities to master the training.

The scores on the Wonderlic Personnel Test are identified and discussed below:

1. It is estimated that 31 of the road design employees would answer 24 or more of the 50 questions correctly. They could be expected to master engineering-level concepts.

2. An estimated 45 employees would score in the 18 to 23 range. They can be expected to master subprofessional engineering work assignments comparable to those involved in the design of roads -- if the training program is effectively designed.

3. An estimated 5 employees would attain scores of 18 or less. They can be expected to have real difficulty with the technology of road design.

Needed Manpower

The percentages of the total work load attributable to each level of performance difficulty indicate the minimum percentages of the total employee force that should be capable of performing work at each level. It is advantageous to employ more personnel in the advanced subprofessional classifications than would be indicated by the overall work load values -- so that all personnel can consistently be engaged in the performance of useful work, regardless of day-to-day variations in the work loads at each level of difficulty.

Findings

The percentages of the total design work load attributable to each level of performance difficulty were obtained from work sampling data. These percentages are tabulated below.

Level of Difficulty	Percentage of Work Load	Percentage of Employees
Beginning- and second-level technicians	33	21
Intermediate-level technicians	19	24
Advanced-level technicians	10	29
Project supervisor and advanced specialist level	38	26
	100	100

If the employees are capable of doing the work attributable to their levels of employment, the capabilities exceed the work loads at all except the highest level. A number of the advanced-level technicians must, obviously, be substituting for the 12 percent shortage at the highest level -- plus the additional shortage that unavoidably is created through performance of less difficult tasks by advanced personnel. No best-staffing ratios can precisely be defined, but the percentages indicated below might be considered reasonable objectives:

Level of Employment	Percentage of Force
Beginning- and second-level technicians	20 to 25
Intermediate-level technicians	25 to 30
Advanced-level technicians	12 to 15
Supervisors and advanced specialists	40

Turnover Rates

The rates of turnover among employees affect the selection of training methods from the standpoints of (1) the numbers of persons that will need to be trained each year and (2) the ways replacement training can best be provided. Self-instructional methods are best suited to most replacement training -- since training can then be given to even one person at any time.

Based on the turnover rates during the period from January, 1968, through July, 1970, the Department can expect a turnover rate of about 15 percent per year. If the current level of employment should be maintained -- thereby reducing the numbers of projects being designed by consultant firms -- 10 to 12 replacement personnel will need to be trained annually. Additional training will need to be provided to fill vacancies at the advanced levels.

Training Needs

Knowledge Statements

As indicated in Chapter Four, more than 240 tasks make up the work systems of road design.

Each of the tasks was analyzed in terms of the specific knowledge, skills and abilities required for its performance. These knowledge-skill-ability requirements were then combined for training needs identification and training program planning purposes. One combination, titled "Mathematics One," is shown in Figure 14.

A review of Figure 14 indicates that basic mathematical knowledge, skills and abilities are needed for certain tasks.

Knowledge Series

A total of 26 combinations of knowledge, skills and abilities are needed for performance of all the work in road design -- plus those attributable to supervision and management.

A review of the titles of 26 knowledge-skill-ability combinations, shown in Figure 15, indicates that three levels of mathematics training are required. In addition, some personnel must be able to interpret surveying data, read contract plans, use manuals of reference and design typical sections, among other things.

Tests

To identify the training needs of the design force, performance-type tests were developed and administered to 13 design employees. Each employee was tested only on those knowledge-skill-ability combinations required by his own work assignments.

The sample group of employees was selected at random from the total headquarters force, and was fully comparable to the total force with regard to age, education, experience and personnel classification characteristics.

Figure 14

A TYPICAL KNOWLEDGE, SKILL AND ABILITY STATEMENT

MATHEMATICS ONE

Knowledge

1. Of the arithmetic used in working with whole, fractional and decimal numbers.
2. Of the procedures followed to convert fractions to decimals and decimals to fractions.
3. Of the rules followed in rounding decimal and fractional numbers.
4. Of the basic rules regarding the "significance of numbers."

Skill

1. In adding machine or calculator operation.

Ability

1. To add, subtract, multiply and divide whole, fractional and decimal numbers accurately and quickly.
2. To calculate percentages.
3. To relate numbers to each other as ratios.

Figure 15

A LISTING OF ROAD DESIGN KNOWLEDGE, SKILL AND ABILITY STATEMENTS

Statement Title	Statement Number
Mathematics One	1
Mathematics Two	2
Mathematics Three	3
Basic Survey Interpretation	4
Advanced Survey Interpretation	5
Plan Reading	6
Basic Drafting	7
Advanced Drafting	8
Manuals of Reference	9
Template Cross Sections	10
Code Basic Computer Inputs	11
Code Complex Computer Inputs	12
Prepare Utility Plans	13
Design Typical Sections	14
Design Alignment and Grade	15
Design Intersection, Rest Area, Scale and Interchange Geometrics	16
Design Contour Grading	17
Design Mass Diagram	18
Design Fencing	19
Design Drainage	20
Design Right-of-Way Limits	21
Design Miscellaneous Features	22
Write Preliminary Special Provisions	23
Prepare Preliminary Estimates	24
Check and Review Plans	25
Cross Check Structure and Road Plans	26

Test Results

The 14 principal training needs are identified by title in Figure 16, together with the number of current personnel needing each type of training. The percentage of the employees who need the capability represented by each training need title for performance of their current work assignments -- and who do not have that capability -- also is shown in Figure 16.

As can be seen, an estimated 60 of the current employees need training in the use of manuals, and 40 need training in mathematics.

Eighty-eight percent of the employees responsible for preparing preliminary estimates need training in that activity. Sixty-seven percent of the employees being assigned typical-section design work are not fully capable of doing the work.

Priorities

Priorities of training needs are established by analyzing three types of data, of which only two are shown in Figure 16. Both the numbers of persons needing training and the percentages of employee groups needing training are important. The third factor is the extent to which a particular course of training, if developed, would be of value to another employee group within the Department.

The training needs in Figure 16 indicate that initial training efforts should be directed toward the use of manuals and other references, mathematics, the preparation of preliminary estimates, drafting and basic designing.

Figure 16

ESTIMATED TRAINING NEEDS OF
MONTANA ROAD DESIGN PERSONNEL

		Number of Persons	Percent of Those Needing Capability
1.	In using manuals	60	75%
2.	In mathematics	40	54
3.	In preparing preliminary estimates	35	88
4.	In interpreting survey data	35	46
5.	In coding computer inputs	35	46
6.	In drafting	30	71
7.	In templating cross-sections	30	60
8.	In reading and interpreting contract plans	25	31
9.	In designing typical sections	20	67
10.	In checking plans	20	67
11.	In designing fences	10	67
12.	In designing contour grades	15	50
13.	In designing mass diagrams	15	50
14.	In designing miscellaneous features	15	50

PROGRAM DESIGN

Alternative Training Methods

References have been made in the above discussions to two methods of training -- classroom and self-instructional. These methods are discussed briefly in this section.

Classroom Method

The traditional method of "education" involves the use of instructors, classrooms, textbooks and chalk boards. The same method is available for use in "training."

Self-Instructional Method

The self-instructional method has characteristics generally opposite those of the classroom. No instructors, chalk boards, lectures or scheduled "classes" are involved.

Self-instructional training can be provided in many forms, such as workbooks, colored slides, audio tapes, workbook and slide combinations, slide-tape-workshop combinations and television tapes. Regardless of the form of the instruction, all self-instructional courses have certain characteristics:

1. The training is set forth in easy-to-understand steps and sequences -- with no steps being too difficult for the specific trainees.
2. The language levels, sentence structures, diagrams and other presentation characteristics are selected specifically for the persons to be trained.
3. Sub-divisions of the training that are easy for some trainees and difficult for others to master, are presented in two or three different ways -- with instructions for the trainees to skip any sections covering material they understand from the first or second presentation.
4. The trainees must actively participate in the training -- by answering questions or performing simulated work operations.

5. The trainees must quiz themselves frequently, and score themselves -- and, to the extent that the quizzes so indicate, they must repeat training units.

6. Each trainee can work at his own pace, going as slowly or as rapidly as actual learning permits.

7. Each trainee can take training according to his own schedule, as distinguished from having to participate in scheduled sessions.

8. Each trainee can continue the training until full capability is developed, as against having to do his best within a specific number of classroom hours.

9. The training can, in most cases, be administered almost anywhere. Trainees need not travel. They can be trained "on the job" -- with the advantages of both formal and on-the-job training techniques.

10. The trainees can be available for work assignments while taking training. They need only interrupt the training for the work period, and start again where they left off.

11. The effectiveness of the training can be determined before the training is implemented. Since the presentations to all persons will be identical -- not subject to the variations that occur in classrooms -- they can be tested before they are used. Improvements can then be made until the desired level of effectiveness is assured.

Training Coverage

Education and Training

The major difference between education and training becomes clear when the subject matter must be defined.

Education is directed toward developing overall knowledge, skills and abilities. No particular employer or work loads are involved. Background information is useful -- such as the history of bridges dating back to the Romans, and previous research efforts in connection with soils mechanics.

Training is directed toward developing specific work performance capabilities for specific employees. The work to be done, the work methods to be used and the quality and productivity levels to be attained are all important. Background information is of little, often no, value.

Work Methods

All training must be based on work methods. And the methods must be complete, fully detailed, logical and consistent. General discussions that leave it up to the trainees to fill in the details are inadequate.

All training must be based on the workmanship levels to be attained. Underdoing and overdoing of work costs money.

Finally, training should ensure proficiency -- the capability to complete reasonable quantities of work within specific time periods.

Work Methods Improvements

Because work methods constitute the principal subject matter of training courses, they must be reviewed before they are used. In most cases, they must be improved -- deleting non-essential steps and re-sequencing the essential steps.

If the training is effective, and high levels of effectiveness can be assured with self-instructional methods, obsolete or inefficient work methods can be perpetuated for many years. In the same way, efficient methods can be introduced for univeral usage.

Training Costs

Training costs money -- as does the lack of training. The objective of training is to reduce the total costs of production by amounts greater than the training costs.

Training costs can be controlled in several ways: (1) by reducing training needs; (2) by selecting training courses that will fill several needs through one effort; (3) by selecting the best methods on cost-result bases; (4) by developing courses in-house, or

through speciality firms: (5) by entering into joint efforts with other agencies, and (6) by using nationwide courses.

Reducing Needs

Certain training needs can readily be reduced without providing training. Non-essential work loads can be eliminated. Work methods can be simplified. Manuals of reference can be improved -- so that they can be interpreted by the persons who must use them.

Course Selections

Courses must be selected to fill priority training needs. But the scope and content of each course must carefully be defined.

One mathematics course can be designed to meet the needs of all employees. Or, three courses can be designed so that most employees will need to study only that which they will use in carrying out their work assignments.

Any course that can be designed to fill the needs of two or more employee groups -- such as the road design and the construction inspection personnel -- will reduce costs. Both the road design and the construction employees must be able to read and interpret contract plans, for example.

Methods Selection

If only a few persons are to be trained, costs can be reduced by using classroom techniques. The work methods must still be identified and improved, and the classroom techniques likely should be more of the workshop than the lecture variety -- to ensure active participation in simulated work assignments. But one instructor can train the total force.

If many persons are to be trained, and particularly if the training must be repeated for several groups, a self-instructional approach can be expected to involve the lowest costs.

Course Development

Developing a prototype of anything complex costs many times that of developing duplicates and modifications -- and effective training courses are highly complex. Also, the first-time mistakes typically are numerous, reducing the effectiveness of the training. One-time costs and first-time mistakes can be reduced by having experienced specialists develop specific courses from previously created models. Computer-input coding courses have previously been developed, for example. To design and prepare a new one, from scratch, would be expensive. To develop a new one based on the prototypes would cost much less.

Joint Efforts

Certain training needs are common to several state highway departments. Among the training needs shown in Figure 16, for example, the specific design courses must almost universally be needed.

States can share the costs of developing common courses, or even prototypes that must be modified for each participating state.

Nationwide Courses

Certain training needs are common to all state highway agencies. A drafting course likely can be developed for use by all highway agencies.

TRAINING PLAN

A general plan for filling the training needs of the road design personnel in Montana has been developed. The plan is based on the characteristics of the work force, the training needs, the alternative training approaches and the cost considerations discussed above.

Operating Function

The road design function is responsible for the work methods, work scheduling and manpower development connected with production. If the designers and supervisors could also be expected to be experts in training technology, valid reasons would exist for creating a training unit in the Bureau of Road Design.

Instead, a highway training committee will need to be established to work with training specialists in:

1. reviewing and approving all work methods, quality standards and productivity guidelines to be used as subject matter for training.
2. reviewing all completed training materials to ensure that the subject matter used complies with that approved for use.

Training Function

Since training needs can be expected to exist in all Department functions, a central training unit is required. Such units have successfully been established in both the research and development functions and the personnel offices of highway agencies. Only two alternative organizational locations for a training function are available in Montana -- as an independent unit reporting to the State Highway Engineer, or as a unit in the Office of Personnel.

It is recommended that a training unit be established in the Office of Personnel.

The training unit should be responsible for:

1. conducting training needs surveys.
2. designing training programs.
3. guiding the appointments of training committees in the operating functions.
4. arranging for the in-house or contract development of training courses.

5. pursuing opportunities for joint-effort training undertakings with other states, and for obtaining useful nationwide courses.

6. guiding and assisting the operating functions in implementing training programs.

Training specialists being very difficult to recruit, the staff can be limited to one specialist for the time being. Additional specialists can be employed as the needs of other functions are identified and as the training work load is defined.

Road Design Program

Training Needs Reduction

The training needs identified earlier in this chapter have already been significantly reduced:

1. A model set of contract plans has been developed to serve as a guide to completed work. Non-essential work has been eliminated. Standard terms, abbreviations and symbols have been adopted. Typical plan sheets, plan sheet layouts and plan sheet sequences have been provided. A paging system and an index system have been adopted.

2. The needs for standard drawings have been identified, and the drawings are essentially complete.

3. The work methods have been improved and diagrammed -- making it easier to do the work without training and making it possible to provide training without further work methods improvements.

4. A design manual has been completed -- using a format, style, language level and other characteristics suited specifically to the Department's current personnel.

The personnel will find it easier to learn many of the work methods on the job, particularly with firm models to use as guides. And it is doubtful that special training in the use of manuals of reference will be needed -- a training-oriented manual having been developed instead. 11/

In-House Courses

The Bureau of Road Design can provide certain courses with no more than limited assistance from training specialists, to fill initial training needs.

Preparing Preliminary Estimates. The techniques involved in estimating, except the ability to calculate, are relatively straightforward. Two or three highly capable estimators can work out the steps, set them forth in a procedural sequence -- using algorithmic diagrams when several options occur. A workshop approach should obtain adequate results.

Computer Input Coding. The Texas Highway Department has self-instructional courses in coding inputs and reading output reports for road design operations. The courses are tailored for Texas, but the courses were tested in Florida and Minnesota with the result that coding capabilities were advanced. Use of the Texas course plus the Montana codes and input forms should fill the needs with little effort.

Plans Checking and Reviewing. This particular training need can be expected to decrease without training as rapidly as the plans themselves are brought into compliance with the standard plans, and as soon as the design manual is made available. To the extent that further training is necessary, one highly capable person should be able to use a few sets of plans and the design manual to conduct workshop sessions -- working with perhaps two persons at a time.

Commercial Courses

The Department can purchase two basic courses, both of which should be tailored specifically for the Department.

11/ There is need to improve both the content and format of the standard specifications.

Mathematics. The personnel already have taken classroom instruction, have attempted to apply that instruction to their work assignments, and still need training. This will, obviously, make it difficult to develop successful classroom training in mathematics. Self-instructional courses have been successful in several highway agencies, and can be prepared for the Department. Mathematics courses can be developed for both road design and construction inspection personnel, reducing the per-employee costs significantly. The courses can be essentially identical for the two employee groups since the rules of rounding to be used, the degrees of decimal accuracy to be attained, and the pay-quantity values will be the same. Only the problems used to make the courses fully work-related will need to be different.

Plan Reading. One course in reading and interpreting contract plans can be developed for both the design and the construction inspection personnel, plus right-of-way agents and other employees. This course has been developed for several states, making it necessary only to rewrite it for the Department, using the Department's model plans as the subject matter.

Completion of the mathematics and plan reading courses should reduce other training needs, such as in checking and reviewing plans, and interpreting survey data -- an integral part of any plan reading course. And these two courses can be expected to make all other training needs easier to fill, since each employee will have a full understanding of the end results to be obtained and the calculations involved.

Remaining Needs

The most difficult training needs to fill will be those classified as drafting and designing. The numbers of employees involved in Montana are too small to justify developing self-instructional courses or workshops in-house or commercially. Classroom methods will also be expensive, since many classroom hours and instructor hours will be required. And the total number of employees cannot substantially be increased by including employee groups.

The most promising approaches would be joint-efforts with other highway agencies -- to share the costs of developing self-instructional courses that can be used year after year. The same needs can be expected to exist in all agencies, and common courses should be

possible. It may be, also, that the Highway Institute currently being developed by the Federal Highway Administration will make such courses available to all agencies.

Immediate Approach. The Department should first provide for on-the-job training of two or three individuals at a time in drafting and designing, using capable personnel as instructors.

Long-range Approach. The Department should explore the possibilities of providing permanent-type courses in drafting and designing through joint efforts with other states, preferably from among the members of the Western Association of State Highway Officials.

Chapter Six

RECOMMENDED PROJECT PLAN

The principal objective of this project was to develop techniques that can be used by highway agencies in undertaking management improvement projects in connection with road design functions.

Many of the details of the research techniques and findings have been omitted from this report--to limit the report to matters of interest to management officials.

A separate reference manual has been developed containing copies of forms used, tabulations and analyses made, diagrams prepared, guidelines to separate phases of the research, and comparable items that would be useful to persons undertaking comparable projects.

This chapter is limited to certain principal guidelines for use by top management officials.

Project Objectives

The objectives of any comparable project should be to ensure that:

1. the design work done is essential to developing acceptable contract plans for roads.
2. the work methods and work processes used are effective and efficient.
3. the manpower and personnel management systems serve to keep the design cost reasonable.

4. the training required for effective work performance is identified and a plan is developed to overcome the needs.

5. the management reporting system serves as an effective instrument of management.

PROJECT ORGANIZATION

An undertaking of the magnitude, and having the potential benefits of a design management improvement project, deserves significant manpower commitments.

Steering Committee

A committee of top management officials should be appointed to:

1. approve the framework of policies, basic procedures and schedules within which the project will be carried out.

2. evaluate findings, analyses, conclusions and recommendations of the project staff.

3. make policy and implementation recommendations to the responsible management officials.

4. provide implementation guidance.

5. evaluate results.

This steering committee should meet for two to four hours approximately once every four to six weeks during the course of the project.

Ad Hoc Committees

Short-term committees of highly knowledgeable design personnel should be used in connection with specific phases of the research--such as work systems improvements, scheduling system improvements and manpower utilization improvements.

Each such committee should be responsible for:

1. defining the problems.
2. participating in the data collections and analyses.
3. participating in developing and testing alternative sub-system improvements.
4. recommending implementations.

These operating committees will need to meet for a day or two at a time, but the members can carry on with their regular work assignments.

Project Staff

A full-time staff is needed to plan, schedule and carry out the research work, and to participate in implementing improvements.

Based on the Montana experience, the project staff should include:

1. a senior, experienced, specialist to provide general direction to the project and to participate in the critical phases of the work.
2. a full-time project manager to provide day-to-day direction to the work underway, and to participate in all phases of the work.
3. a full-time assistant project manager.
4. at least one full-time technician to collect and tabulate data, develop diagrams and presentation materials, and code data processing inputs.

General Work Plan

The project itself should cover all elements of the total design management system--as though each sub-system is a component of a large and complex machine.

As with a machine, each component should be treated one at a time, with no effort on the part of the project staff to comprehend at any time all of the detail of the total

system. The best that can be done with the system as a whole is to deal with the end products of each sub-system.

But, the improvements should be made in a certain general sequence, as indicated in Figure 17.

Phase One

The first efforts must be directed at identifying the principal characteristics of the existing system, such as the organization, available policies, procedures and manuals, and the number of persons employed by classification and organization unit.

Phase Two

The first improvement efforts to be made should be to provide guidelines for effective productivity:

- development of model contract plans.
- development of needed standard drawings.
- preparation of a design manual.

Completion of the model plans and the drawings will provide a base for all other work. Sections of the design manuol can also be completed early and used as a base. The full manual can be completed only when all work systems are complete.

Phase Three

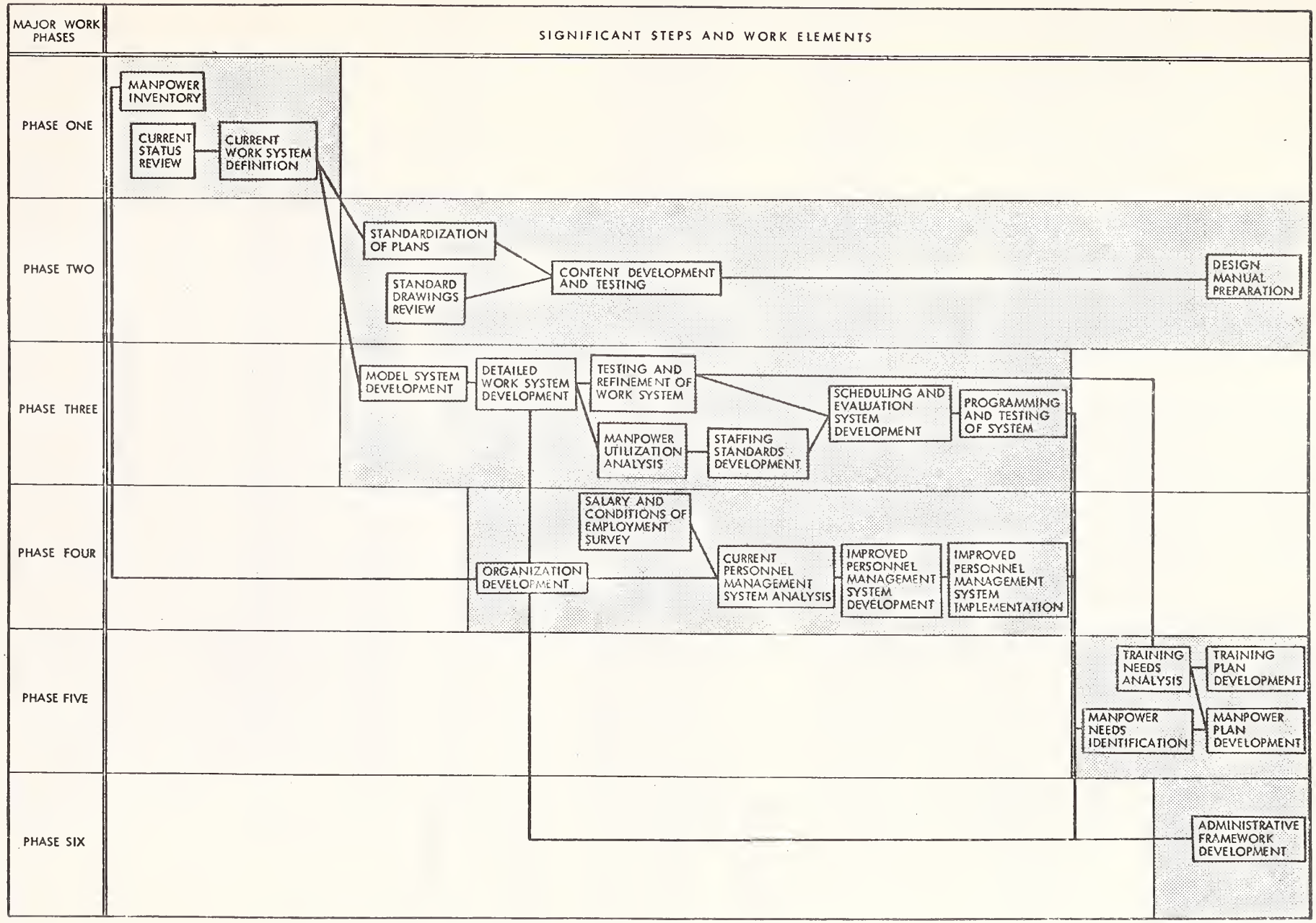
The third phase should be directed toward the work methods and work controls.

Each work method should be identified, diagrammed, analyzed, improved and, if necessary, tested. Work loads should be measured, by activity. Productivity values should be established for each activity work load--using "best estimates" as starting points.

The work scheduling, status evaluation, controlling and management reporting system should be designed and tested

Figure 17

DIAGRAM OF THE REVISED WORK PLAN
FOR THE DEVELOPMENT OF A DESIGN MANAGEMENT SYSTEM



Phase Four

The next effort should be directed toward the personnel management function.

With the activities, tasks and work loads fully identified, personnel classification decisions can readily be made. Key personnel classifications can be selected for salary survey purposes, and surveys can be completed.

The basic terms of employment can then be worked out:

- Personnel classifications.
- Promotional criteria and plans--based on performance values.
- Salary plans and salary increase criteria--based on performance values.

Phase Five

With known work loads, effective work methods and activity sequences, work scheduling and controlling systems, and the personnel classification plan available for use as base data, the next two steps can be completed: (1) manpower needs identification and (2) training program design.

Phase Six

All sub-systems having been completed, the final design management system can be completed:

1. The organization structure.
2. The operating policies and administrative procedures.
3. A design management manual with guides to staffing, scheduling, controlling and evaluating.

Project Schedule

The work contemplated above requires many persons to change their ways of operating. They need time to evaluate findings, study the analyses and proposed changes, and to adjust

their thinking. They need to participate actively in the project itself--as distinguished from having new plans and methods presented and ready for use.

Two Years

The total project, including all improvement implementations, can be completed in about two years, with participation by the operating managers and top management officials.

Depending on the effectiveness of the existing sub-systems, the project time can be reduced or extended by two or three months. But a reasonably firm schedule should be established as soon as data on the existing situation are available.

Third Year

A follow-up evaluation should be made after the total system has been implemented for about one year. Refinements missed during the implementation period, with special reference to productivity guidelines and manpower needs, can then be worked out.

Completed System

The completed system should include:

- A design manual, to guide designers in making and documenting design decisions.
- A design management manual, to guide managers relative to administrative policies and procedures, and staffing standards.
- A scheduling and controlling system--to define project priorities, define work loads, establish manpower needs, provide activity and project completion dates, and permit comparisons to be made between planned and actual completion dates, manpower commitments and design costs.

- A personnel management system designed to support the objectives of the road design function.
- A manpower plan--to indicate future work loads and manpower needs.
- A training plan--to improve the productivity rates.